Does the Universe Exist if We Don't Observe It?

20 Biotech Geniuses | Saturn's Mystery Moon: Titan

Discover

VOL. 23, NO. 6

JUNE 2002

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What Really Killed the Dinosaurs?

It may be time to stop blaming that asteroid

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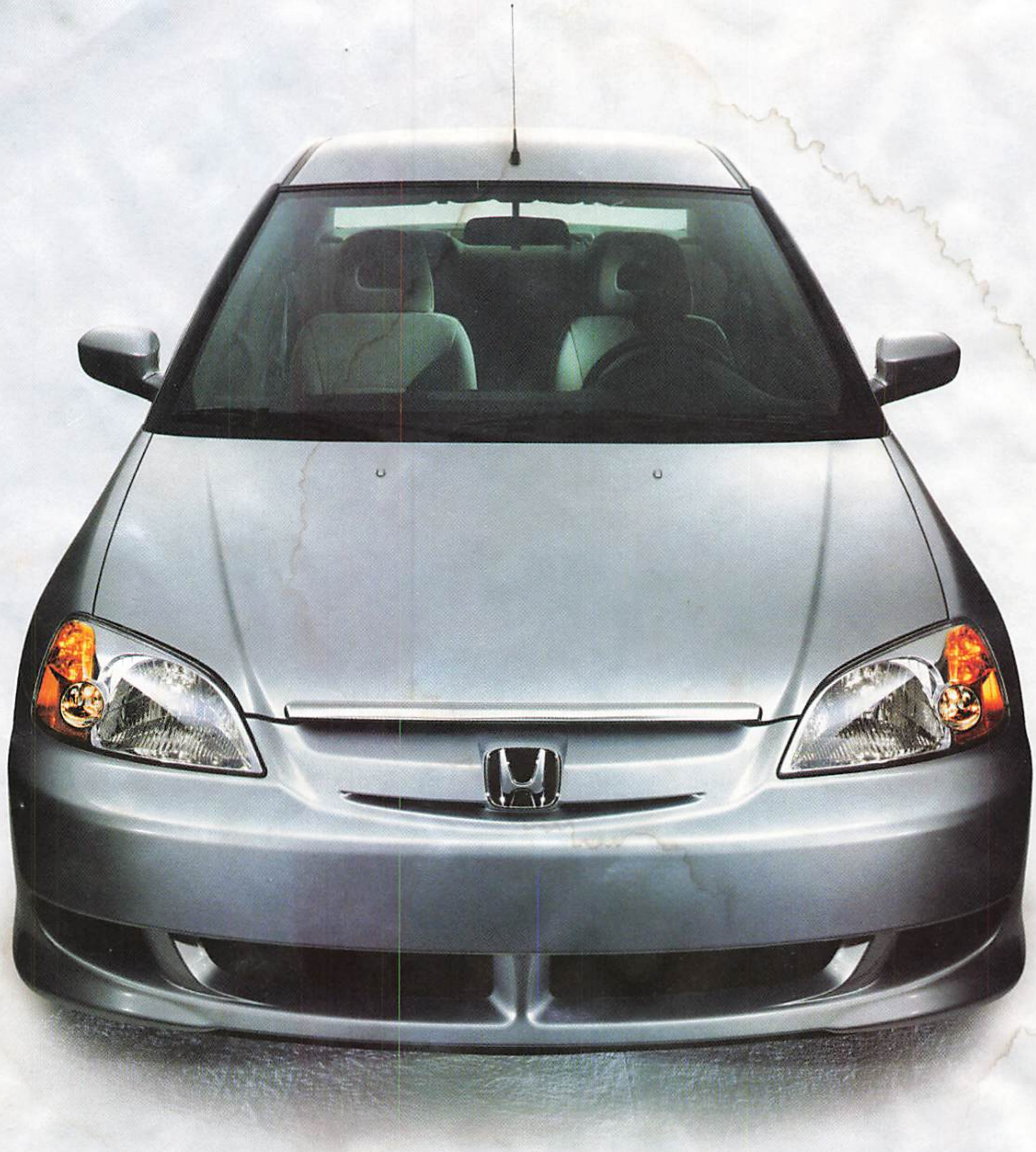

honda.com 1-800-33-Honda *Based on EPA mileage estimates for Civic Hybrid with MT (46 mpg city/51 mpg highway). Actual mileage may vary. ©2002 American Honda Motor Co., Inc.

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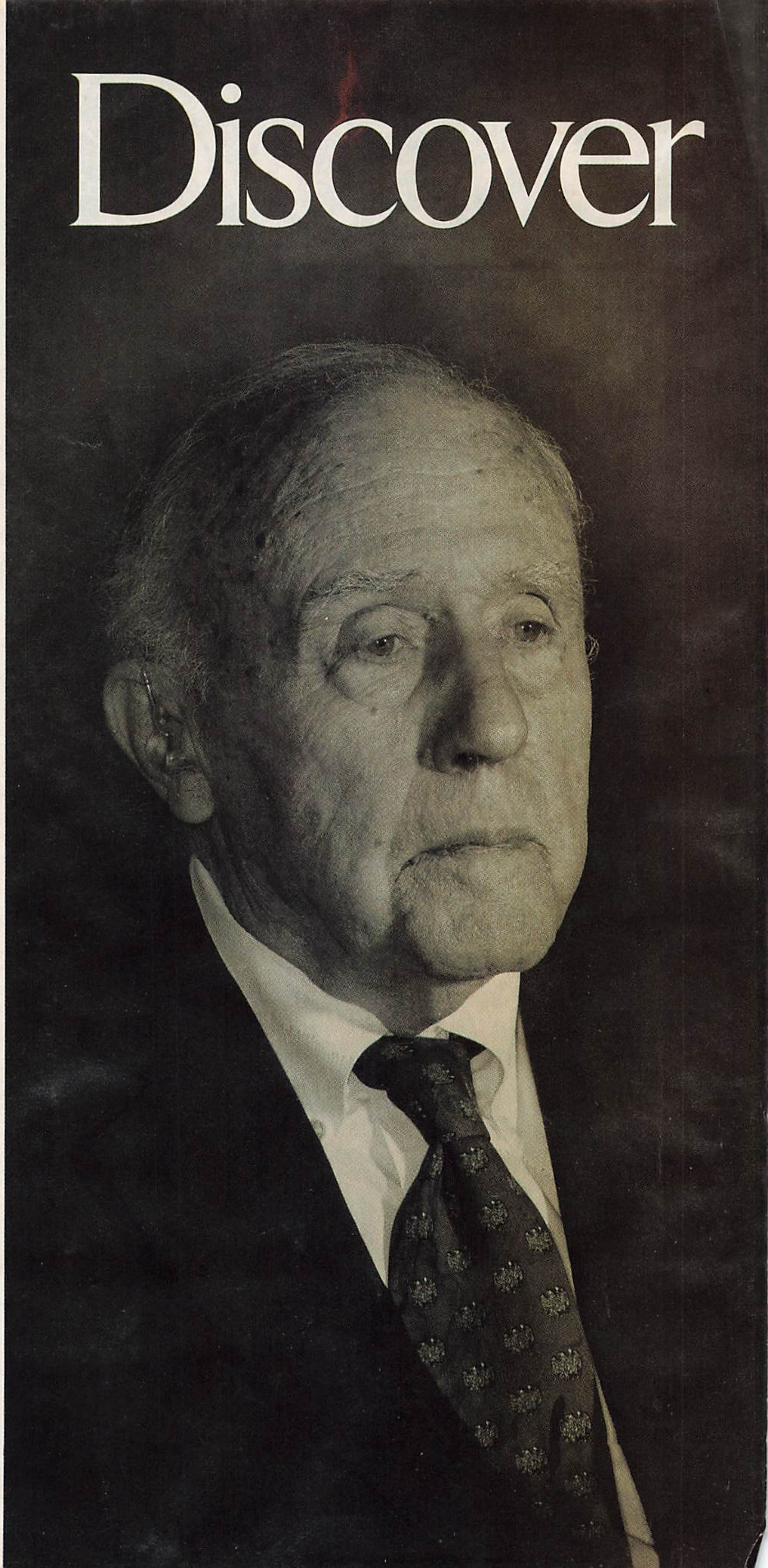

RIGHT: JOHN WHEELER WAS A PROTÉGÉ OF NIELS BOHR, MATCHED WITS WITH ALBERT EINSTEIN, AND NOW ASKS QUESTIONS TO CHALLENGE THE BEST MINDS OF THE 21ST CENTURY. SEE PAGE 44.
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PHOTOGRAPH BY DAN WINTERS

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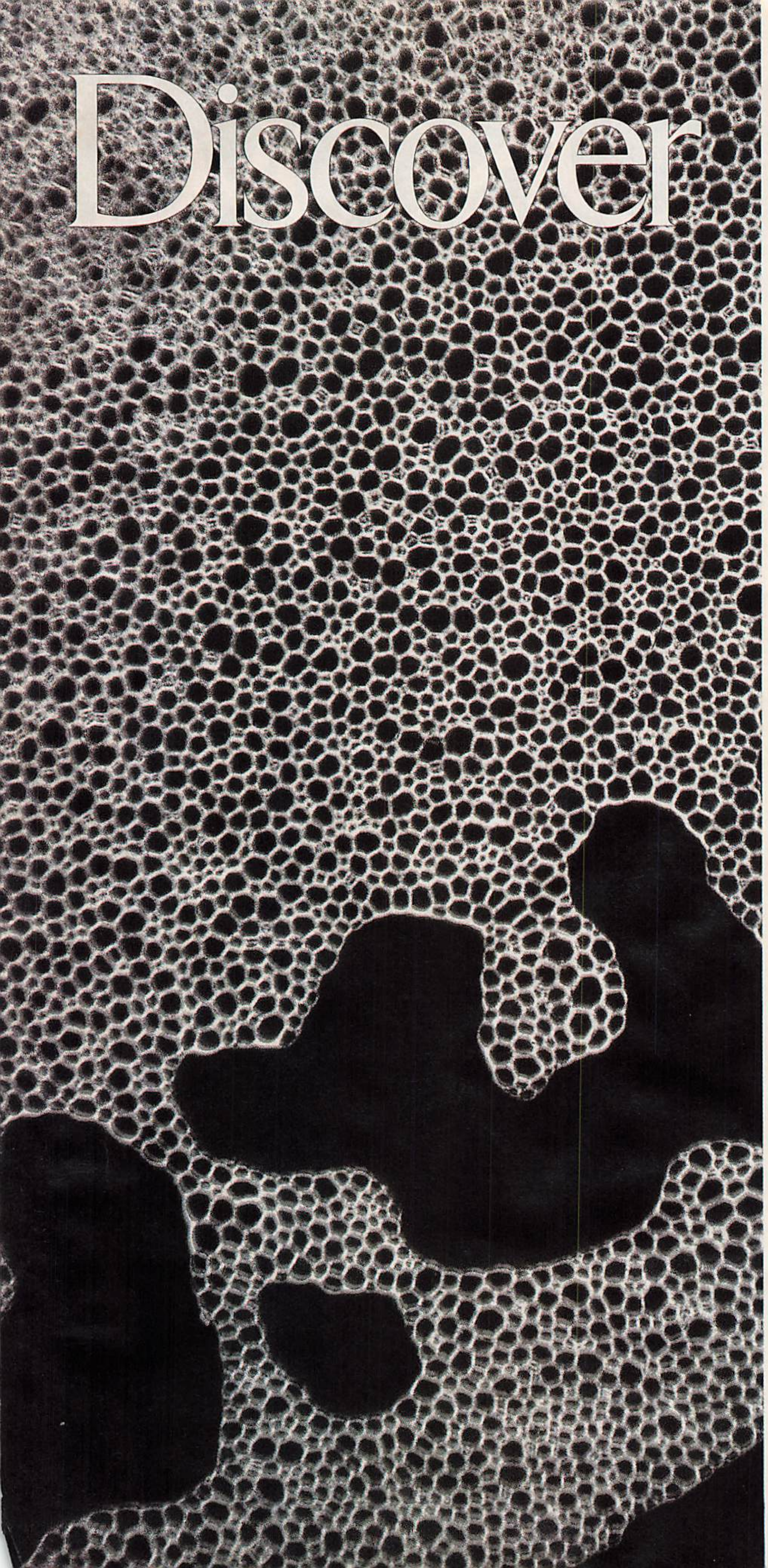

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PHOTOGRAPH BY FELICE FRANKEL

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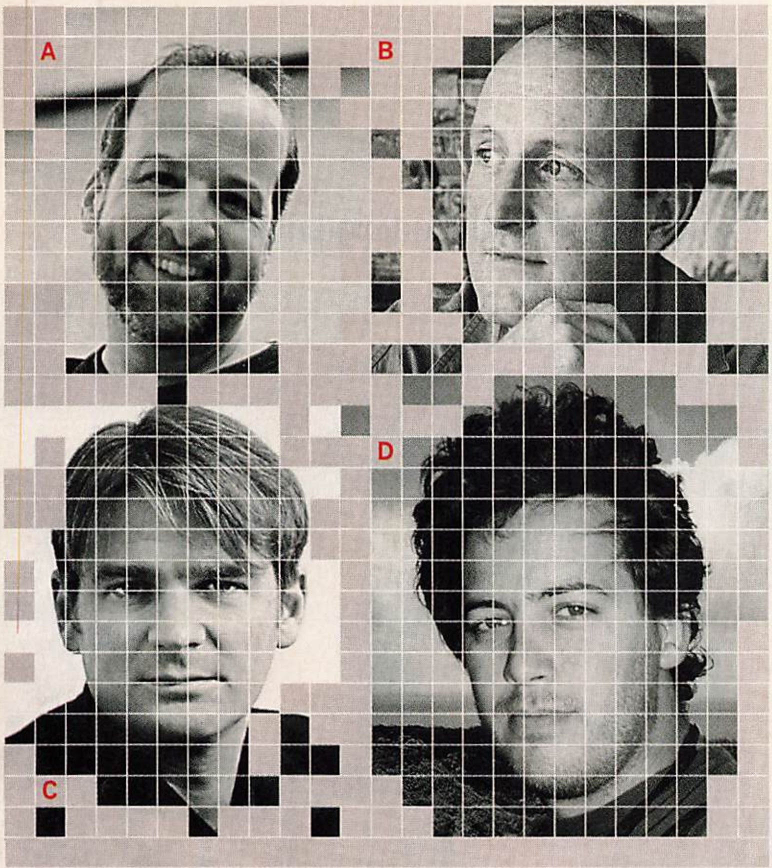

PHOTOGRAPH: DUNCAN, PHOEBE KAYLOR.

BARRY YEOMAN (A) was captivated not only by the beautiful reptiles he encountered in a marshland reserve in Michigan ("Can Turtles Live Forever?" page 60) but also by the scientist who has devoted his life to studying them. "When you're talking to Justin Congdon, you get the sense that in his cosmology, turtles are right at the center, and people are just circling in an outer orbit," Yeoman says. "This guy loves turtles the way somebody else might love Nascar racing or Paris."

JAMES GURNEY (B) has been drawing Jurassic and Cretaceous creatures since he was a kid ("What Wiped Out the Dinosaurs?" page 36). He has never grown bored, because scientists keep changing their minds about what dinosaurs looked like. "They may be extinct, but they don't stay dead—we're always looking to resurrect them in our minds," he says. "As an illustrator my job is to go where the camera can't, to be a witness to the invisible."

DAVID EWING DUNCAN (C) was amazed by how many biotech wizards he found when he went looking for them ("20 Biotech Geniuses to Watch," page 68). And he was equally awed by their accomplishments. They are, he says, "amazing, brilliant people, coming up with innovative discoveries, one after another, at an almost dizzying rate." He was also pleased to learn that they are cautious about the impact of their work. "These are not scientists plunging headlong into the next discovery; they're really giving it a lot of thought."

MORAD BOUCHAKOUR (D) had never seen a turtle up close before he photographed Blanding's, Painted, and Common Snapping turtles for this issue of *Discover*. But it didn't take him long to realize how tragic it was to witness an almost immortal animal dying by accident. "Researchers see these turtles grow up over many years, so when one gets hit by a car, it's truly a big loss."

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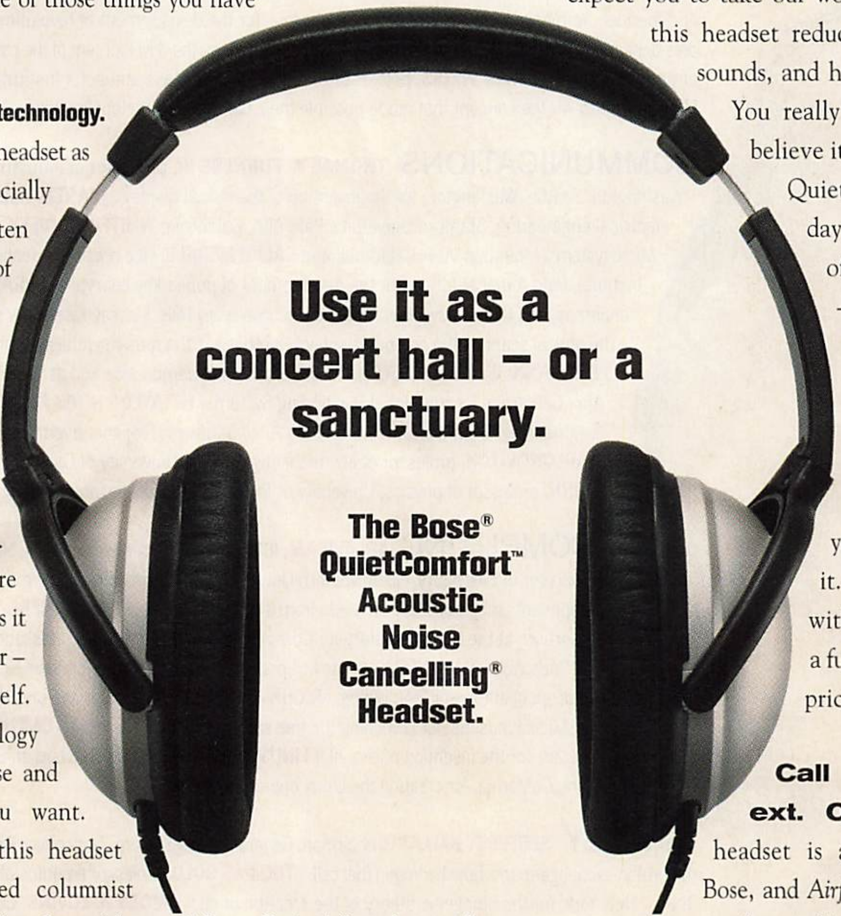

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AND THE DISCOVER AWARDS NOMINEES ARE . . .

The 13th Annual Discover Magazine Innovation Awards will be announced in next month's issue. One winner or team from each of five categories will be chosen from the following extraordinary finalists:

AEROSPACE **ROBERT Q. FUGATE,** senior scientist, atmospheric compensation, Air Force Research Laboratory, Starfire Optical Range, Kirtland AFB, New Mexico, for adaptive optics. | **KATHLEEN HOWELL,** professor of aeronautics and astronautics, Purdue University, West Lafayette, Indiana, and **MARTIN W. LO,** LTool task manager, Jet Propulsion Laboratory, Pasadena, California, for using manifolds to compute spacecraft trajectories. | **PAUL MacCREADY,** chairman and founder, AeroVironment Inc., Monrovia, California, for the development of revolutionary aircraft. | **BURT RUTAN,** president and CEO, Scaled Composites LLC, Mojave, California, for the development of the canard wing and other innovative aircraft designs. | **RAINER WEISS,** professor of physics at the Massachusetts Institute of Technology, Cambridge, Massachusetts, for the concept that made possible the Laser Interferometer Gravitational-Wave Observatory.

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COMMUNICATIONS **THOMAS A. FURNESS III,** professor of industrial engineering, University of Washington, Seattle, Washington, for the invention of the retinal display. | **MARTIN HELLMAN,** professor emeritus of electrical engineering, Stanford University, Palo Alto, California; **WHITFIELD DIFFIE,** distinguished engineer, Sun Microsystems, Mountain View, California; and **RALPH MERKLE,** vice president, technology assessment, Foresight Institute, Palo Alto, California, for the development of public-key encryption. | **RAYMOND KURZWEIL,** founder, chairman, and CEO, Kurzweil Technologies Inc., Wellesley Hills, Massachusetts, for multiple innovations, including the optical scanner, the computer-speech synthesizer, the music synthesizer, and voice-recognition software. | **BRADFORD W. PARKINSON,** professor emeritus of aeronautics and astronautics, Stanford University, Palo Alto, California, for the Global Positioning System. | **H. TAYLOR HOWARD,** professor emeritus of electrical engineering, Stanford University, Palo Alto, California, for the invention of the satellite-dish TV. | **ELI YABLONOVITCH,** professor of electrical engineering, University of California at Los Angeles, and **SAJEEV JOHN,** professor of physics, University of Toronto, for proposing and building the first photonic crystal.

COMPUTING **ARI AVIRAM,** IBM Research, Yorktown Heights, New York, and **MARK RATNER,** professor of chemistry, Northwestern University, Evanston, Illinois, for proposing in 1974 that computer components might one day be made from a single molecule. | **TIM BERNERS-LEE,** director, World Wide Web Consortium at the MIT Laboratory for Computer Science, Cambridge, Massachusetts, for the creation of the World Wide Web. | **PAUL HORN,** senior vice president, IBM Research, Yorktown Heights, New York, for developing the concept of autonomic computing. | **RICHARD STALLMAN,** founder and president, Free Software Foundation, Boston, Massachusetts, for launching the free software movement. | **RAY TOMLINSON,** principal engineer, BBN Technologies, for the invention of e-mail. | **LINUS TORVALDS,** senior software engineer, Transmeta Corporation, Santa Clara, California, for creating the Linux operating system.

ENERGY **GEOFFREY BALLARD,** chairman, General Hydrogen Corp., Vancouver, British Columbia, for developing the proton-exchange-membrane hydrogen fuel cell. | **THOMAS GOLD,** professor emeritus of astronomy, Cornell University, Ithaca, New York, for the abiogenic theory of the creation of oil. | **AMORY B. LOVINS,** CEO, Rocky Mountain Institute, Snowmass, Colorado, for teaching us that conserving energy is better than building nuclear power plants. | **ENDERS ROBINSON,** professor emeritus of geophysics, Columbia University, New York, New York, for revolutionizing seismic oil prospecting. | **TAKEHISA YAEGASHI,** senior general manager, Power Train Planning Department, Toyota Motor Corporation, Toyota City, Japan, for designing the power train of the Prius, the first mass-produced hybrid-engine automobile.

MEDICINE **JOHN CHRISTIAN BAILAR III,** professor emeritus, University of Chicago, Chicago, Illinois, for raising the level of discussion about responsibility in medical research and other critical public health issues. | **PATRICK O. BROWN,** professor of biochemistry, Stanford University, Palo Alto, California, for the invention of the DNA micro array. | **H. ROBERT HORVITZ,** professor of biology, MIT, Cambridge, Massachusetts, for proving the theory of apoptosis (programmed cell death). | **SIR PAUL NURSE,** interim CEO, Cancer Research UK, London, England, for discovering the universal machinery that regulates cell division in all eukaryotic organisms, from yeasts to human beings. | **PAUL RIDKER,** associate professor of medicine, Brigham and Women's Hospital, Boston, Massachusetts, for establishing that inflammation is a major cause of heart attacks. | **GERALDINE SEYDOUX,** associate professor of molecular biology and genetics, Johns Hopkins University, Baltimore, Maryland, for identifying the mechanisms that generate germ cells, the precursors to adult reproductive organs. | **JAMES THOMSON,** professor of anatomy, University of Wisconsin, Madison, Wisconsin, for developing the first human embryonic stem-cell lines. | **IAN WILMUT,** joint head of the Department of Gene Expression and Development, Roslin Institute, Midlothian, Scotland, for cloning the first mammal. | **WISE YOUNG,** director of the W. M. Keck Center for Collaborative Neuroscience, professor of cell biology and neuroscience, Rutgers University, Piscataway, New Jersey, for discovering that steroids administered shortly after an injury can preserve some spinal-cord function.

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— Ryan Bendixen

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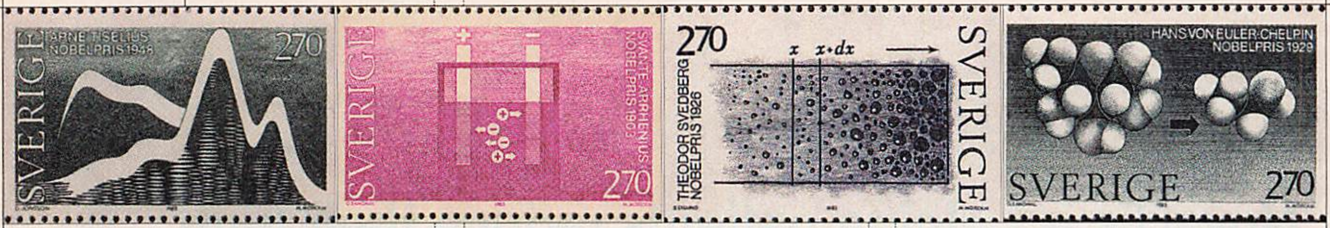
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Issued in 1983.

POP GOES THE UNIVERSE

Although I'd like to be able to tell you that I completely understood physicist Alan Guth's inflation theory of how the universe began ["Guth's Grand Guess," April], I am left with two nagging questions: (1) If things (dog, house, planet) can pop into existence, can they also pop out of existence (like single socks)? And (2) into what physical space did the universe pop?

ADAM SCHULTZ—Portland, Oregon

Editor's note: *(1) Yes. (2) The one you're in.*

The cover of *Discover*'s April issue displays the words "Where Did Everything Come From?" as if the answers are to be found within. But ultimately, the article "Guth's Grand Guess" does not satisfy. Like the novice philosopher who is told that God made the universe, the original question is answered by referral, and we are no wiser than before. In this case, we are given the analogy of the virtual particle that pops in and out of existence in the space-time reference of our universe. But the explanation begs the question of the reference or underlying reality from which our universe sprang. What is the nature of that vacuum?

GARY ROBINSON—Marshalltown, Iowa

Editor's note: *As we suggested in the "Letter from* Discover*" that preceded the article, that may be the last great mystery.*

In "Guth's Grand Guess," Brad Lemley gives the impression that inflation theory is complete and has pretty much been proven correct. Although that theory is certainly the gold standard in cosmology these days, problems remain. Perhaps the most significant is that the properties of the primordial fields believed to have driven inflation have to be entered into the equations by hand. But the theory does not explain *how* the fields got those properties or even where the fields came from. So, as Stephen Hawking often points out, we still need a theory of the initial conditions. The story also seems to indicate that there are no alternatives to inflation. But in March 2001, Paul Steinhardt—one of the pioneers of inflation theory—along with Neil Turok, Justin Khoury, and Burt Ovrut, proposed a powerful alternative called the "ekpyrotic" model, which is based in M-theory. Of course, this new theory could go down in flames. But your story should not have given readers the impression that inflation is *it,* case closed. Even Guth does not believe that.

TOM YULSMAN, Associate Professor
School of Journalism and Mass Communication
University of Colorado at Boulder

Brad Lemley's April feature "Guth's Grand Guess" ought to be a required text for university English majors. It is about one of the most perfect pieces of literature I've ever read.

DAVE ZES—Long Beach, California

The remark ["Letter from *Discover,*" April] that Alan Guth's idea that the universe could come from nothing "leaves little room for most of the world's religious teachings" is based on the assumption that religious teaching is nullified when its theory of cosmology is in doubt. But origin myths are merely one part of religion. The overwhelming bulk of religious teaching is dedicated to helping us live meaningfully in the here and now. Science writers who have no theological background should refrain from rehashing antireligious generalities and stick to their topic. Now that the pope himself no longer delivers opinions on physics, it's surely not too much to expect the science community to show similar reserve in airing simplistic ideas about religion.

BOB SCHILDGEN—Berkeley, California

"Guth's Grand Guess," while quite interesting, was too cautious about the potential of inflation theory. If the theory is correct, the universe arose from nothing in accordance with the rules of quantum mechanics, but apparently some scientists question the validity of such a profound creation. The void that was "space" before the universe was truly an infinite space. Within an infinite space, anything that is possible will happen at every instant in "time." In fact, it will happen an infinite number of times at any given time; such is infinity. It makes perfect sense, therefore, that our universe exists and that it is actually accompanied by an infinite number of other, identical universes (and hence an infinite number of universes that are only minutely different). I believe there was a brief reference to this possibility in the article, but it did not fully explain the possibilities that inflation theory, in conjunction with quantum mechanics, has to offer.

PAUL EMERSON FRANZ—Boulder, Colorado

I noticed the following sentence on page 70 in the article "Notes From a Parallel Universe" [April]: "One retired commercial diver answered all my questions with an uninterrupted monologue on gravity (it pushes rather than pulls, he said)." The article dismissed the unnamed man as a science crank. I also noticed on page 36 ["Guth's Grand Guess"] this statement: "A false vacuum is characterized by a repulsive gravitational field." On page 38 there is this sentence: "If these observations are right, Guth says, they offer proof that gravity can

(continued on page 87)

HELP FROM DISCOVER

Letters: Address letters to *Discover,* 114 Fifth Avenue, New York, NY 10011-5690; e-mail to editorial@discover.com. Include the writer's full name, address, and daytime phone number. Letters may be edited for length and clarity and may be published in the magazine or on its Web site. Due to the volume of mail we receive, we cannot respond to every letter. **Customer service/subscription inquiries/back issues:** For questions about your subscription or obtaining back issues, call toll-free 800-829-9132; outside the U.S., 515-246-6952. Or write to *Discover,* P.O. Box 37283, Boone, IA 50037-0283. **Submissions:** We cannot be held responsible for unsolicited manuscripts or materials of any kind. **Internet:** *Discover* Web site (www.discover.com). **Note to subscribers:** *Discover* occasionally allows selected companies to send mail to our subscribers. If you would rather not receive these mailings, please send your current mailing label or an exact copy to *Discover,* P.O. Box 37283, Boone, IA 50037-0283.

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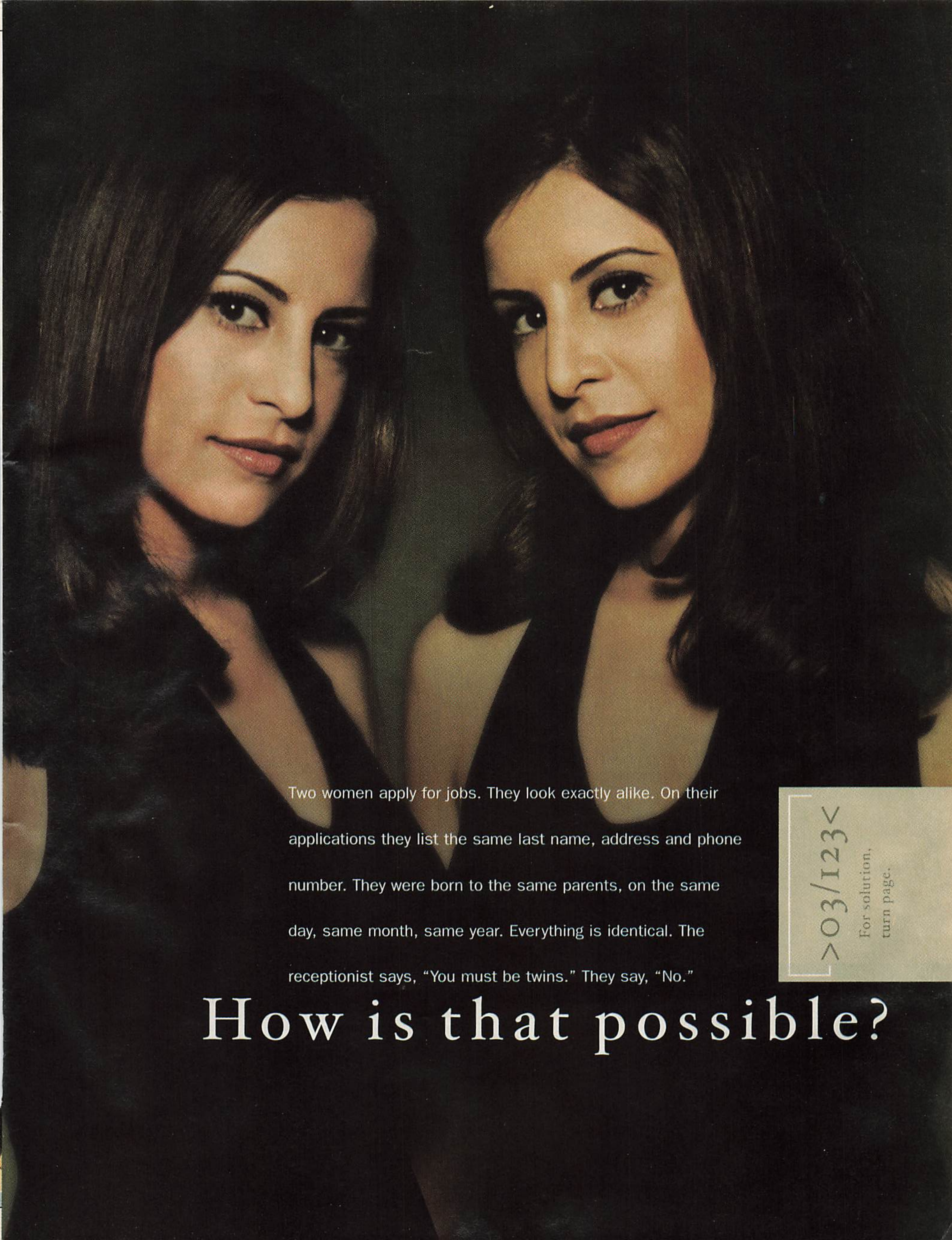

Two women apply for jobs. They look exactly alike. On their applications they list the same last name, address and phone number. They were born to the same parents, on the same day, same month, same year. Everything is identical. The receptionist says, "You must be twins." They say, "No."

How is that possible?

>03/123<

For solution, turn page.

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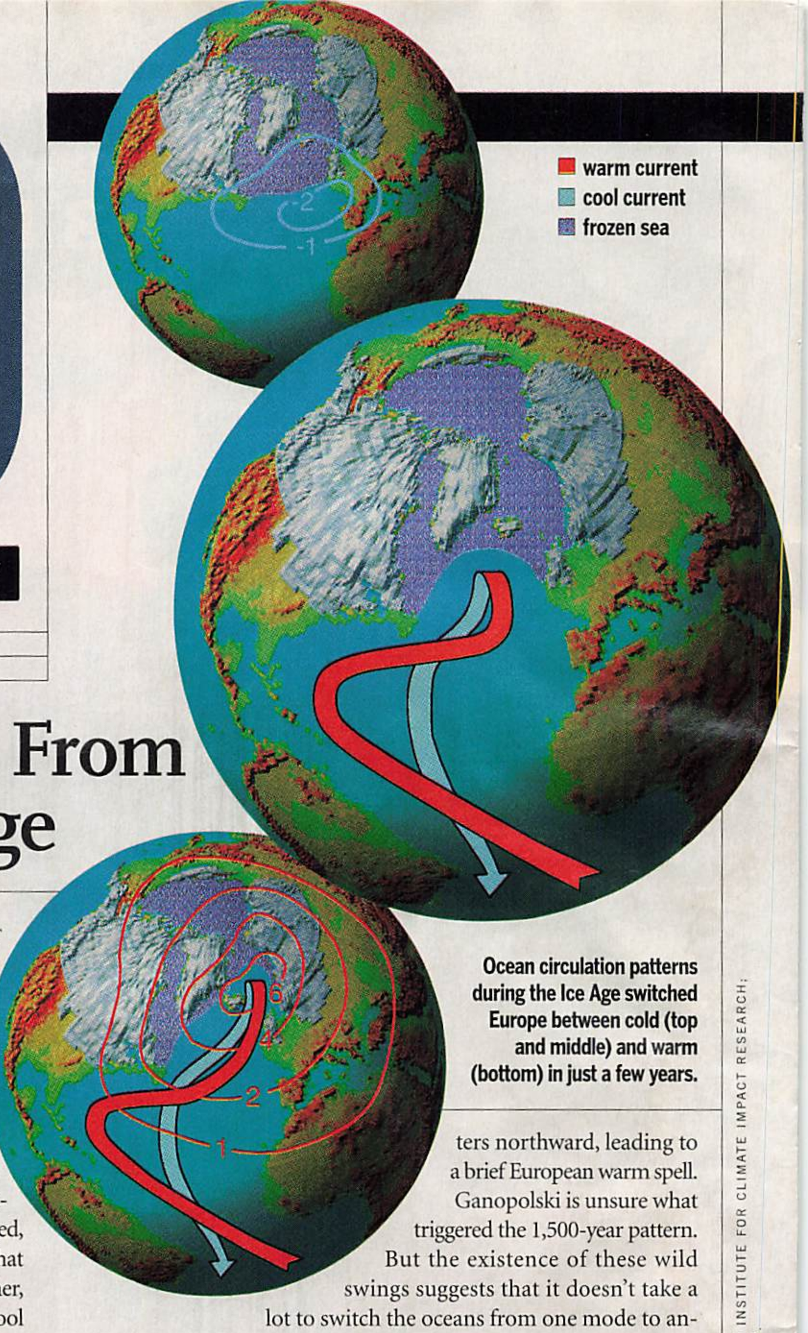
NEWS ABOUT SCIENCE, MEDICINE, AND TECHNOLOGY

Chaotic Warnings From the Last Ice Age

THE LAST ICE AGE, FROM 120,000 TO 10,000 YEARS AGO, WAS NOT IN FACT always cold: During 20 brief interludes, temperatures shot up 10 to 18 degrees within a decade. Andrey Ganopolski and Stefan Rahmstorf, climatologists at the Potsdam Institute for Climate Impact Research in Germany, think they have figured out why. Chaotic weather variations occasionally triggered a cascade of changes that switched temperatures from cold to warm.

Ganopolski and Rahmstorf developed a computer model showing how the change could have happened. During the glacial era, the Gulf Stream current in the Atlantic normally turned before reaching Iceland. But every 1,500 years or so, the circulation abruptly changed, sending warm waters all the way to Europe. The researchers found that random fluctuations would sometimes produce times of cool weather, when relatively little freshwater melt flowed into the ocean. If these cool spells happened to coincide with an additional chilling factor—say, a periodic episode when the sun was slightly dimmer than usual—the reduction in freshwater would cause saltier, denser ocean water to sink. This effect would destabilize the Gulf Stream and pull the surface waters northward, leading to a brief European warm spell. Ganopolski is unsure what triggered the 1,500-year pattern. But the existence of these wild swings suggests that it doesn't take a lot to switch the oceans from one mode to another. "Strong changes in the system may not necessarily be triggered by strong external perturbation," he says. In other words, pollution and other environmental damage wrought by humans could spawn huge, unpredictable climate changes. *—Fenella Saunders*



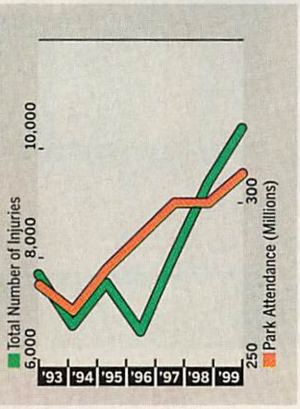
Ocean circulation patterns during the Ice Age switched Europe between cold (top and middle) and warm (bottom) in just a few years.

EVOLUTION'S BIG BITE Mark Purnell is trying to rethink the nature of our early ancestors by peering into the mouths of 400-million-year-old fish. Contrary to the common theory that we descended from fierce predators, he believes our aquatic antecedents were in fact algae-grazing browsers. Purnell, a paleontologist at the University of Leicester in England, focused his study on heterostracans. These extinct jawless fish, which swam in coastal waters more than 100 million years before the dinosaurs appeared, were among the first animals to acquire toothlike structures. Some scientists say the choppers were used to attack creatures that had not yet evolved defenses against dentin. But Purnell's examination of heterostracans suggests that their rows of "teeth"—actually maple leaf-shaped structures derived from their scaly armor plating—would have been ineffective for that purpose. The proto-teeth pointed outward, so the fish could not have seized prey or chewed it. Rather, Purnell argues, the animals used the barbs as filters. "They were drawing water currents into the mouth and over the gills, gathering microscopic food particles such as algae and zooplankton, which they then consumed," he says. He scoffs at the idea of heterostracans gnashing their teeth, tearing apart trilobites: "I doubt these animals would have been able to tear their way out of a wet paper bag. They were filter feeders, not ferocious at all." *—Josie Glausiusz*

PHOTOGRAPHS: TOP, COURTESY OF ANDREY GANOPOLSKI/POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH; BOTTOM, COURTESY OF MARK PURNELL/UNIVERSITY OF LEICESTER.

Data Points

AMUSED TO DEATH As some amusement parks compete to provide even higher, faster, scarier rides, a day of thrills is getting a bit riskier, says Robert Braksiek, an emergency room physician at the Hennepin County Medical Center in Minneapolis. Yet overall, a day at the park is still one of the safest recreational pastimes. Braksiek compiled data on parks around the country and found that the number of injuries increased by 95 percent over the last three years of the study, as total attendance grew by 6.5 percent. Roller coasters appear to cause the lion's share of fatalities, at least one-third of the total. "Engineers are trying to build the biggest, fastest ride, with the highest g-force," Braksiek says. The risk of death stands at one in 150 million rides, and injuries occur only once every 124,000 rides, on average. But he notes that the risks of riding on a roller coaster are much smaller than those a person racks up driving to the amusement park. *—Lauren Gravitz*



COLD FUSION REDUX?

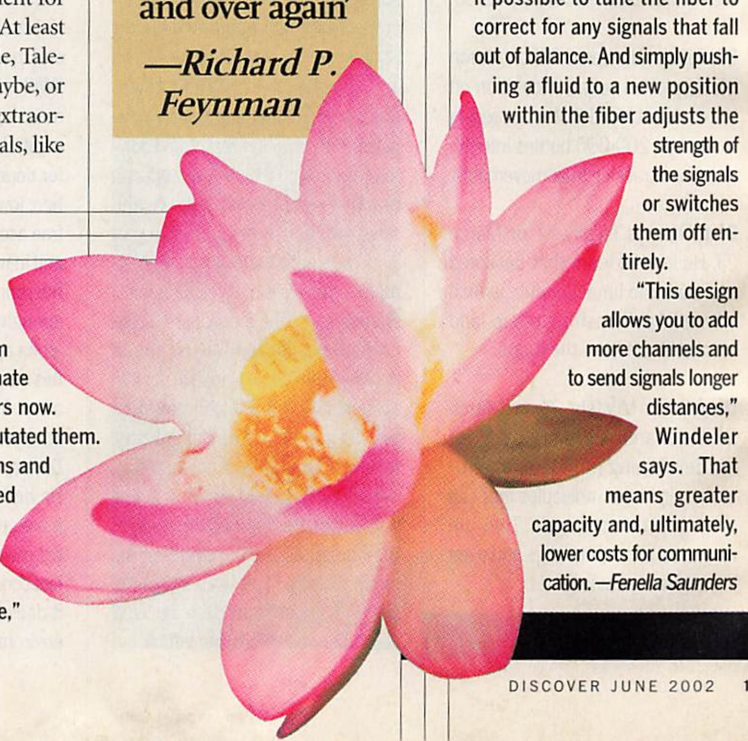
TURNING BUBBLES INTO ENERGY SOUNDS LIKE AN ALCHEMIST'S FOLLY—yet that is what Rusi Taleyarkhan says he has done. Taleyarkhan, a nuclear engineer at Oak Ridge National Laboratory, and colleagues zapped a coffee-can-size canister of acetone with neutrons to create microbubbles. Next they blasted the bubbles with sound to make them expand and then collapse violently, releasing flashes of light and heat. This process, sonoluminescence, also triggered pockets of nuclear fusion, the energy source that powers the sun—or so Taleyarkhan claims.

If so, he may be on track toward solving our energy worries. But a second team of Oak Ridge physicists, Dan Shapira and Michael Saltmarsh, could not replicate the results. Fusion reactions should release a shower of neutrons. "We saw only a small change in the background count," Saltmarsh says, which he attributes to echoes from Taleyarkhan's own neutron source. Taleyarkhan responds that his critics used an inappropriate detector: "We've run the experiment, starting from scratch, more than a hundred times. We are comfortable with the results."

Lawrence Crum of the University of Washington, a sonoluminescence expert who has followed Taleyarkhan's work, is also skeptical. "These experiments could possibly get to temperatures sufficient for fusion, but the evidence here for these claims is weak," he says. At least eight other labs are racing to repeat the experiment. Meanwhile, Taleyarkhan is pondering other uses for his bubbles—a bomb, maybe, or something more benign. "We've got a device that can induce extraordinary temperatures and pressures. It could transform materials, like the way nature turns carbon into diamonds." *—Kathy A. Svitil*

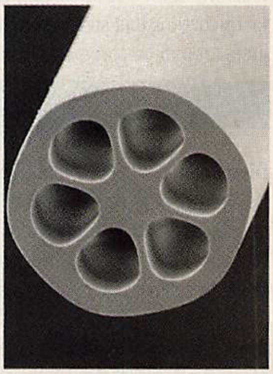
> 'When we see a new phenomenon we try to fit it into the framework we already have.... It's not because Nature is really similar; it's because the physicists have only been able to think of the same damn thing over and over again'
>
> *—Richard P. Feynman*

ANCIENT LOTUS RETURNS TO LIFE Jane Shen-Miller, a plant biologist at the University of California at Los Angeles, has reanimated centuries-old seeds of the sacred lotus. She recovered the seeds from a dry lake bed in China's Liaoning Province and managed to germinate four of them. Two plants have been growing for two and three years now. Cumulative exposure to low-level radiation in the soil apparently mutated them. Both plants produced abnormal offspring with thin underwater stems and floppy, discolored leaves. But it's amazing that the seeds germinated at all. Common food grains last only a few years before rotting. "To remain alive, the lotus seeds need to repair damage accumulated over hundreds of years. If we can figure out the lotus's repair mechanisms and transfer them into crops, we may be able to reduce famine," says Shen-Miller. *—Kathy A. Svitil*



LIQUID LIGHTS THE WAY

ROBERT WINDELER HAS A BETTER recipe for the fiber-optic cables that carry today's telecommunications: Just add liquid. Current optical-fiber systems do not amplify different wavelengths of light equally well, which can cause errors in signal transmission. As in a home stereo, if one wavelength gets too loud, it distorts terribly. Windeler and his colleagues at OFS Laboratories and at Lucent Technologies's Bell Laboratories, both in New Jersey, developed a fluid-filled fiber that keeps everything on the same level. The upgraded fiber has a ring of holes surrounding a solid core (below). Windeler places a small amount of liquid into the holes and seals the ends. Heating the liquid alters which wavelengths will dissipate as they travel through the core, making it possible to tune the fiber to correct for any signals that fall out of balance. And simply pushing a fluid to a new position within the fiber adjusts the strength of the signals or switches them off entirely.



"This design allows you to add more channels and to send signals longer distances," Windeler says. That means greater capacity and, ultimately, lower costs for communication. *—Fenella Saunders*

PHOTOGRAPHS: CENTER RIGHT, COURTESY OF BELL LABORATORIES/LUCENT TECHNOLOGIES; BOTTOM, COURTESY OF KENILWORTH AQUATIC GARDEN.

LANDMARKS

June 9 100th anniversary of the opening of the nation's first Automat—a mechanized system for dispensing food—by the Horn and Hardart Coffee Company of Philadelphia.

June 14 30th anniversary of the executive order, issued by the Environmental Protection Agency, banning the insecticide DDT.

June 16 100th anniversary of the birth of geneticist Barbara McClintock, who won a 1983 Nobel Prize for discovering that some genes can jump around on chromosomes.

TRIBUTES

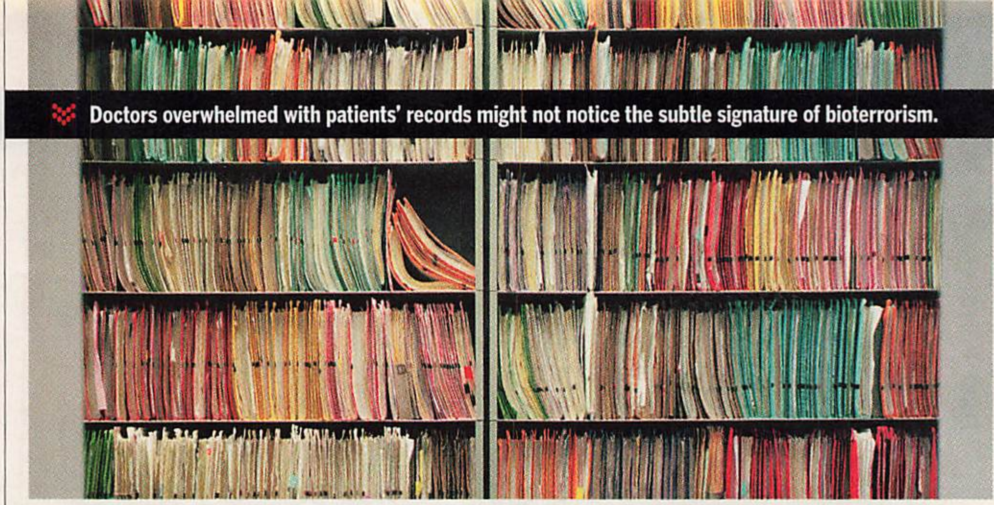
Died Peter Meyer, 82, on March 7. Using balloon-borne instruments, he investigated cosmic rays and found that some of these "rays" are positrons, the antimatter twins of electrons.

Died Gilmore Schjeldahl, 89, on March 10. He built *Echo 1,* the first communications satellite, from a mix of Mylar and adhesive. The 100-foot inflatable ball bounced radio and TV signals across the country in 1960.

Died Dean Bumpus, 89, on March 14. He plotted ocean circulation off the eastern United States by tossing more than 200,000 bottles into the water and tracking their movements.

Died Thomas J. Kelly, 72, on March 23. He led the team that designed and built the lunar module, which allowed Apollo astronauts to land on and lift off from the moon.

Died César Milstein, 74, on March 24. He shared a 1984 Nobel Prize for developing monoclonal antibodies, immune molecules that can home in on exact targets. They are now used in cancer drugs and even in pregnancy testing kits.



Doctors overwhelmed with patients' records might not notice the subtle signature of bioterrorism.

AN ARTIFICIAL EYE ON BIOTERROR

IF ANOTHER BIOTERROR ATTACK arrives, we might not know it for some time. A cluster of related symptoms at hospitals in the same region could signal the early stages of an outbreak. But as the anthrax episode demonstrated, it's not easy for doctors to recognize the larger significance of scattered cases when each seems routine on its own.

The Biomedical Security Institute, run jointly by the University of Pittsburgh and Carnegie Mellon University, has developed an artificial-intelligence program to place medical events in a larger context. The Real-time Outbreak Detection System, or RODS, sifts through hospital admissions records, compiling patients' symptoms, the area where they live, and what they do. Then the software looks for hidden patterns. "It could be that everything looks fine, except that there's been a 20 percent increase in admissions among postal workers who worked last Sunday in a particular zip code," says computer scientist Andrew Moore of Carnegie Mellon.

Such broad searches can find correlations even on normal days, so RODS uses complex statistical tests to reduce false alarms. If an event still seems unusual, the system alerts a public-health expert. During a two-year trial covering 20 hospitals in western Pennsylvania, RODS successfully detected a natural influenza outbreak. The system got a high-profile test in Utah in time for the Olympics; fortunately, nothing showed up. Now Moore and his colleagues aim to cover a wider geographic area and include over-the-counter medication sales and even veterinary data. *—Fenella Saunders*

SIM SURGERY

JULIEN ETIENNE, AN ENGINEER AT CARdiff University in Wales, thinks current medical training methods are inconsistent and uncomfortable for doctors and residents alike. So he and his colleagues at Cardiff's Manufacturing Engineering Center have developed computer-sculptured polymer models on which residents can practice laparoscopic surgery and other precision techniques. "Our goal is to re-create the operation environment as realistically as possible," Etienne says. The models are based on high-resolution MRI scans of healthy individuals from the neck to the upper thigh. A 3-D fabricator, used to build prototype parts for industry, transforms the MRIs into casts of skin, organs, and skeletal structures. The bodies can be prodded and poked, then disassembled to evaluate the mock surgery. "This is a much safer way to track a trainee's progress," says Etienne. *—Maia Weinstock*

Monkey Users Are Losers

THE 1980S IMAGE OF COCAINE AS A TOTEM OF SOCIAL SUCCESS IS NOT ONLY PASSÉ but a reversal of reality, according to a new study. Researchers at Wake Forest University School of Medicine in Winston-Salem, North Carolina, housed several macaque monkeys alone for a year and then placed them in groups of four. "Within three months a clear pecking order had been established," says pharmacologist Michael Nader, who led the project. During the social rearrangements, high-ranking monkeys showed a 20 percent increase in a key brain receptor for dopamine, a chemical that mediates feelings of both well-being and addiction; low-ranking simians displayed little change. Then Nader gave the monkeys free access to cocaine. "The lower-status ones injected themselves more often and in higher doses," he says. The farther down the social ladder a monkey was, the more likely it was to inject itself enough to get hooked. None of the alpha apes developed habits. Does this mean high-ranking humans have a built-in immunity to addiction? "It's not that simple—look at the Robert Downey Jr.'s of the world," says Nader. He believes vulnerability depends more on a general sense of social enrichment. "That translates less to socioeconomic status for humans than it does to the general quality of the environment." *—Jocelyn Selim*

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COFFEE VS. CAVITIES

JAVA LOVERS, REJOICE. ITALIAN researchers have discovered that coffee may prevent cavities. Gabriella Gazzani, a pharmaceutical chemist at the University of Pavia, and her colleagues measured how well *Streptococcus mutans* bacteria, the primary cause of tooth decay, stick to saliva-and-coffee-covered balls of enamel that mimic the composition of teeth. Every type of brew reduced the number of bacteria picked up by the enamel balls. Roasted coffees did the best, staving off some 98 percent of bacteria that glom onto untreated teeth. The researchers still do not know which of coffee's several chemical components is responsible for the drink's bacteria-fighting properties, but they have ruled out caffeine: Regular coffee proved less effective than decaf. *—Maia Weinstock*

Ask the Wizard

Why do bubbles in soda rise from only certain spots on the glass? ***MARIA FERRER, MASNOU, SPAIN***

Paul Treichel, professor of chemistry at the University of Wisconsin in Madison, replies:

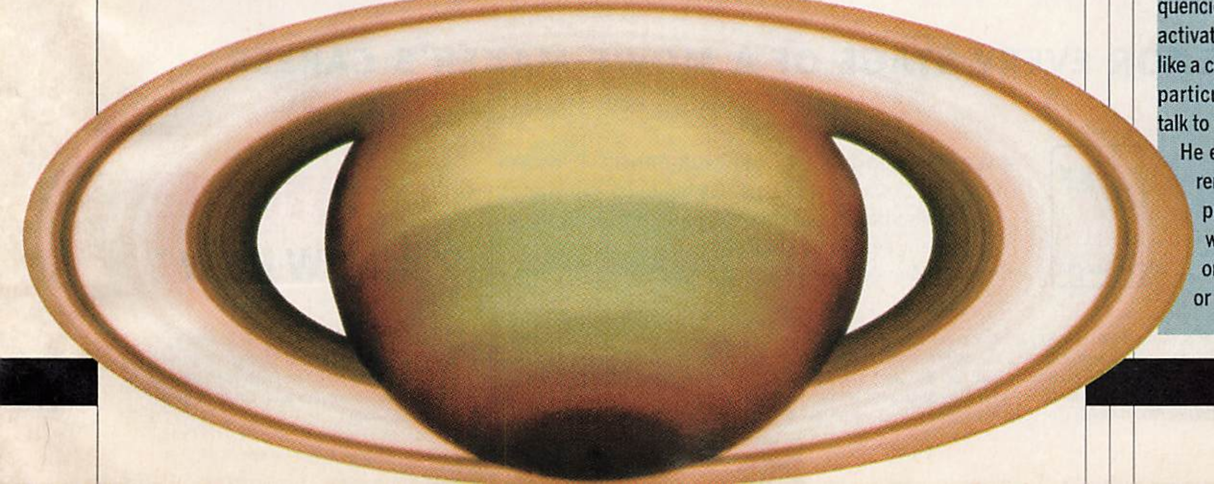
The effervescence of bubbly beverages—including soda, beer, and champagne—comes from dissolved carbon dioxide. These beverages are bottled (or canned) under pressure, which increases the amount of dissolved carbon dioxide. When the container is opened, the pressure is released. Bubbles of gas form as the system returns to equilibrium. Molecules of dissolved carbon dioxide are initially dispersed evenly throughout the liquid. Once the pressure of the bottled-up system is released, however, gas molecules migrate to certain spots and coalesce there to form bubbles. These are much more likely to arise on the bottom or sides of the glass than within the liquid because bubbles form preferentially at surface imperfections, spots where the glass is pitted, scratched, or etched. Such locations are called sites of nucleation. Once bubbles begin to form, they attract other carbon dioxide molecules until the bubble grows so large that buoyancy causes it to break off and rise. The aggregation of carbon dioxide at those nucleation sites continues until the system reaches equilibrium—that is, the drink becomes "flat." Sites of nucleation also initiate the formation of crystals in a solution, such as sugar crystals in honey or maple syrup, and the formation of raindrops in clouds.

> **'The reward of the young scientist is the emotional thrill of being the first person in the history of the world to see something or to understand something'**
> ***—Cecilia Payne-Gaposchkin***

Imagining Saturn Without Its Rings

ASTRONOMERS AT THE VERY LARGE Telescope atop Cerro Paranal in Chile recently captured the most detailed view of Saturn ever seen from the ground. The planet was at full tilt, meaning the rings were at their most prominent. The timing was exceptional on a cosmic scale as well: New research suggests Saturn's showpiece is a temporary thing. Jeff Cuzzi, a planetary scientist at NASA's Ames Research Center, suspects the rings are only a few hundred million years old, making them just one-twentieth as ancient as the planet itself. He bases the revised birth date on observations showing that the rings lack the dust that would have accumulated if they had formed with the planet 4.8 billion years ago, as astronomers long believed. Cuzzi notes that the architecture of the rings is always changing, a sign that the system is quite young and an indication that we are seeing a spectacle that is short-lived—in astronomical terms, at least.

—Maia Weinstock



SET THE REMOTE TO "DNA"

RESEARCHERS AT MIT AND ENGENEOS in Waltham, Massachusetts, have engineered a strand of DNA to react at the push of a button. Biomedical engineer Shuguang Zhang and his colleagues constructed a genetic switch by exploiting DNA's basic double-helix structure. They chemically attached a cluster of gold atoms to a loop of DNA whose loose ends are normally bound together into a twisted helix. "It looks like a lollipop," Zhang says. The gold atoms act as a miniature antenna, absorbing radio waves. Those waves heat the gold cluster, which in turn splits the bonds between the two halves of the DNA. When the radio signal turns off, the DNA cools and links back up. The MIT team is developing antennas that would respond to different radio frequencies so they can selectively activate multiple strands. "It's like a cell phone, where only the particular person you want to talk to will answer," Zhang says. He envisions expanding the remote-control approach to proteins and enzymes, which could turn genes on or off to suppress diseases or to initiate gene therapy.

—Fenella Saunders

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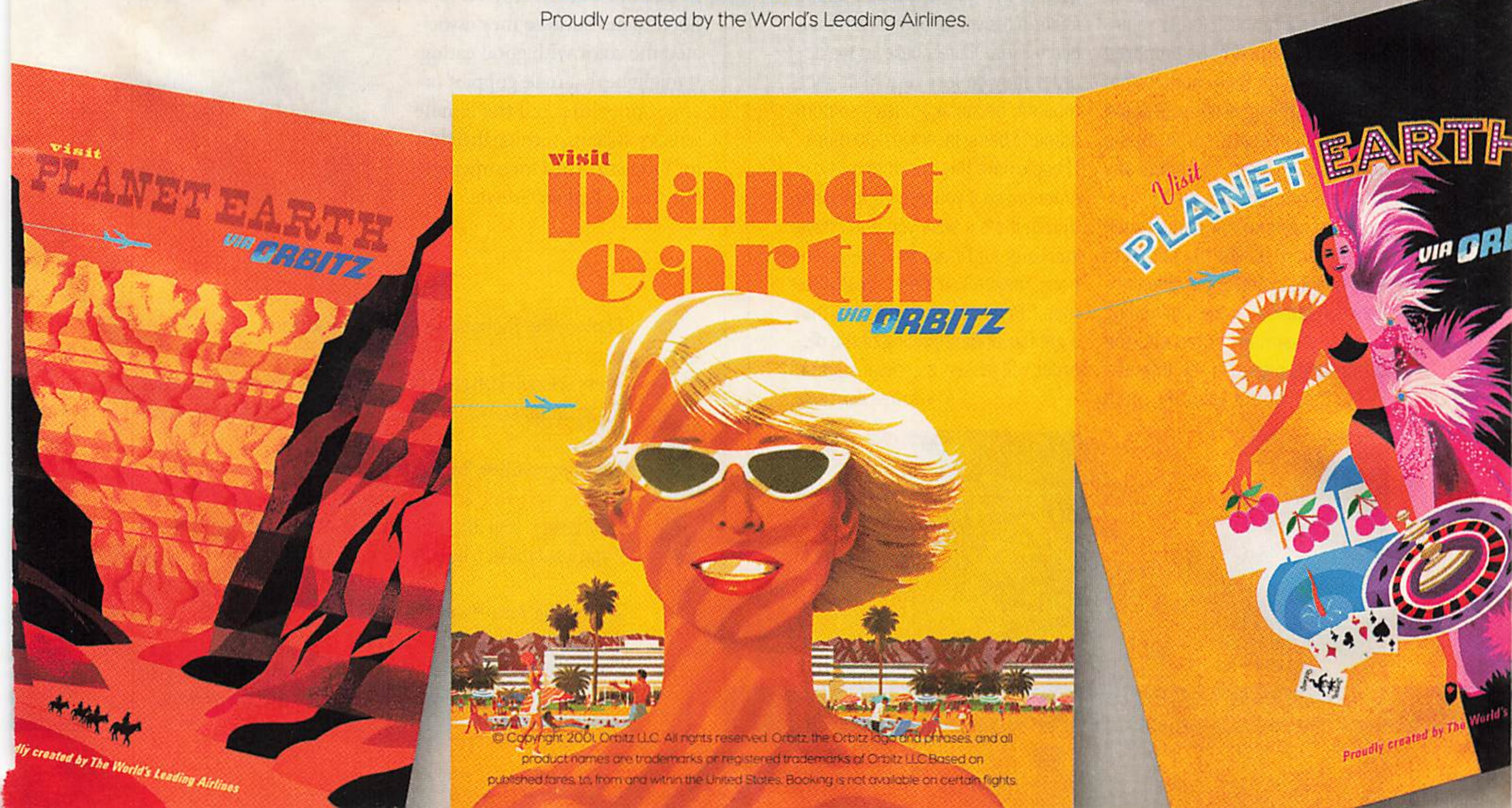
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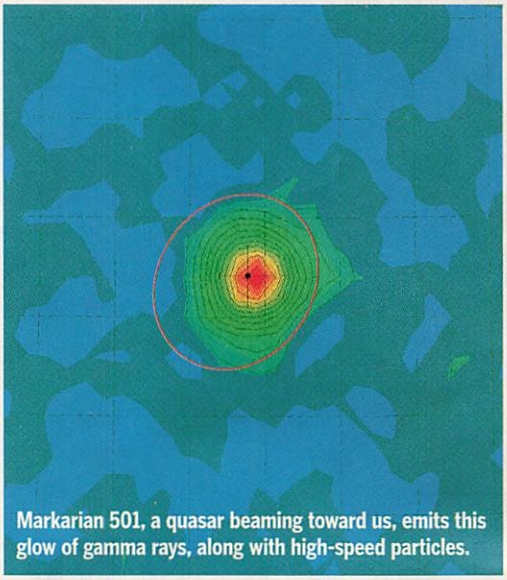
A WRINKLE IN SPACE-TIME Extremely potent cosmic rays—high-speed atomic fragments that pack as much energy as a bullet—reach Earth from quasars billions of light-years away. That perplexes cosmologists, whose calculations suggest the rays should collide with the bits of microwave radiation that fill the universe and be destroyed long before they arrive. Some researchers consider the conundrum so strange that it can be solved only by trashing Einstein's theory of relativity. But Richard Lieu, an astrophysicist at the University of Alabama in Huntsville, says the theory is fine, once you understand how to combine it with quantum theory.

Lieu invokes the example of clocks and moving trains to explain the flaw in current thinking. According to Einstein, a clock on a moving train appears to be ticking more slowly than normal from the perspective of a stationary observer on the platform. Furthermore, any error in timekeeping measured by the moving clock would be magnified; at 99.5 percent the speed of light, a clock running a second behind would appear 10 seconds slower than it actually is to the unmoving observer. In this interpretation, the cosmic rays are moving so swiftly that quantum jitters—the smallest possible units of time—appear to expand into large chunks of temporal uncertainty that obscure the exact speed or energy of the cosmic rays.

If it is impossible to measure the speed of the cosmic rays, Lieu argues, we cannot predict how they will interact with the microwave radiation. In fact, that fundamental uncertainty could offer an escape so they do not interact at all. "If so, then the cosmic rays can coast through the microwave background," he says. The persistence of the cosmic rays is not an attack on Einstein, therefore, but another tribute to the subtlety of his ideas. *—Josie Glausiusz*

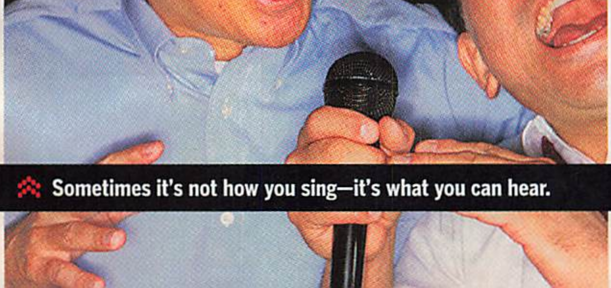


Markarian 501, a quasar beaming toward us, emits this glow of gamma rays, along with high-speed particles.

NOISE TO THE EARS

TO MOST PEOPLE, MUSIC IS THE SWEETest of sounds. But to a small subset of humanity, music is nothing but noise. Neuropsychologist Isabelle Peretz of the University of Montreal has pinpointed the reason: People suffering from amusia, as the disorder is known, are unable to interpret small changes in pitch. Peretz ran tests on 11 volunteers who claimed to be unmoved by music. All of them had normal hearing, were highly educated, and even had received some music lessons as children. None had any problem recognizing lyrics, language, or nonmusical sounds such as animal cries. Yet the subjects were unable to detect the difference between familiar songs containing slightly dissonant notes and the same songs played in key. Interestingly, they could identify pitch changes in spoken sentences, such as the difference in inflection between a statement and a question, perhaps because the intervals between notes in speech are much larger that those in music.

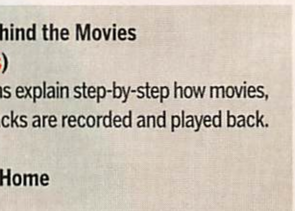
These results suggest amusia may be a genetic disorder analogous to dyslexia, caused by subtle faults in the wiring of the brain's auditory cortex. Peretz believes the disorder may be less rare than once thought, because amusics seldom admit to being insensitive to music. "People have this idea that music is emotion, so if you don't appreciate music, it's because you don't have emotions. And if you don't have emotions, maybe you are not really human," Peretz says. She hopes that a greater understanding of the disorder will lessen its social stigma.
—*Josie Glausiusz*



Sometimes it's not how you sing—it's what you can hear.

YOU LOOK GOOD ENOUGH TO EAT

THE WAY TO A GUPPY'S HEART SEEMS TO BE THROUGH ITS STOMACH. While working in Trinidad, biologist Kimberly Hughes of the University of Illinois at Urbana-Champaign and behavioral ecologist Helen Rodd of the University of Toronto noticed that the orange-spotted fruit of the Cabrehash tree—a favorite guppy food—resembles the markings on many male guppies. Female guppies tend to prefer males with such orange spots. Coincidence? Hughes and Rodd investigated by dropping colored disks into guppy-infested streams. Both sexes were most strongly drawn to orange disks, suggesting that the attraction to orange colors predated female preference for orange males. Most likely, Hughes says, females began opting for orange-hued mates because they associated the color with good eating. It might be that male guppies' orange spots hijacked the female sensory systems, turning their lust for food into a lust for something else too. *—Lauren Gravitz*



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The Ig Nobel Prizes, awarded for research that "cannot or should not be reproduced," prove scientists have a sense of humor.

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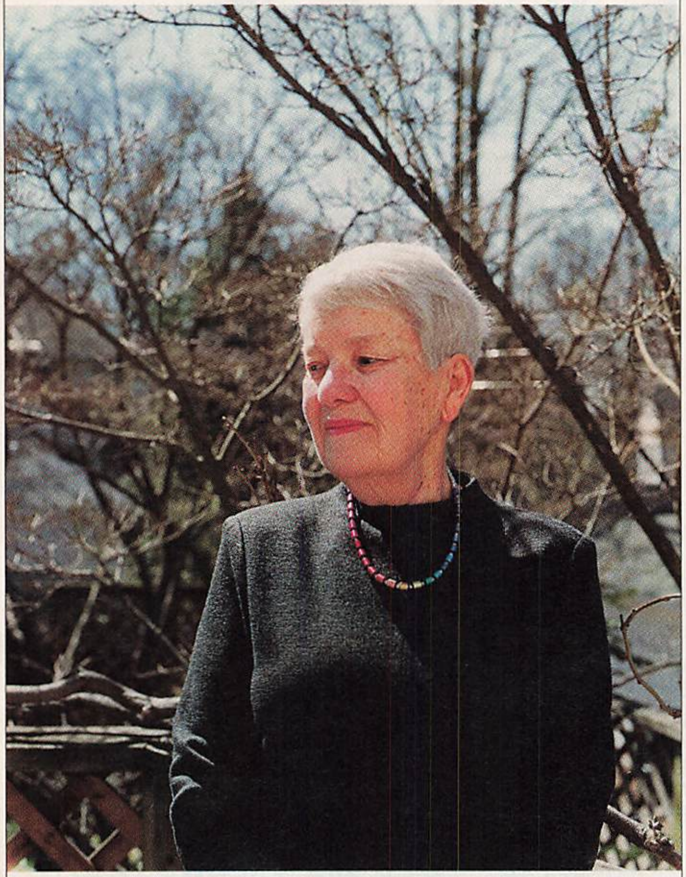


DOYENNE OF DARK MATTER

When Vera Rubin was 14, she fashioned a telescope out of a cardboard tube and began scanning the night sky. Her early enthusiasm paid off in 1950, when, as a 22-year-old mother of a month-old baby, she made headlines with a provocative theory that the universe is rotating. Her later observations helped spark a remarkable realization: The vast majority of matter in the universe is invisible, or "dark." Now 73, Rubin continues her cosmic exploration at the Carnegie Institution in Washington, D.C. She shared her insights with *Discover* associate editor Josie Glausiusz.

How did you realize the universe is filled with invisible matter?

In a spiral galaxy like our own, a couple hundred billion stars orbit the center. Spirals appear to thin out toward the edges, so the gravitational pull on the outer stars should be weaker. Everyone assumed objects near the edges orbit more slowly. But that is not what I found: Even at the periphery stars orbit at high velocities. There has to be a lot of mass to make the stars move so rapidly, but we can't see it. We call this invisible mass dark matter.

Do we know what this unseen stuff consists of?

Absolutely not. Particle physicists are trying to do in their laboratories what the universe is doing on a very large scale, so they are continually building more powerful and larger detectors. But they're looking for something that's much rarer than a needle in a haystack.

Could dark matter control the fate of the universe?

If there is enough of it, then the universe might ultimately stop expanding and collapse. We think that there isn't enough dark matter to halt the expansion, however. In fact, it looks as if there is a cosmological constant, a hidden energy whose effect is to make the expansion speed up.

What are you studying these days?

Still galaxies, but more peculiar ones. About 10 years ago I discovered a galaxy in the Virgo cluster in which half the stars go clockwise and half go counterclockwise—in the same disk. I also started studying polar ring galaxies, which have rings of stars and gas over their poles. It's difficult to understand how these objects form.

What lies in wait for our own galaxy, the Milky Way?

We and Andromeda, the closest large galaxy, are approaching each other. In about 2 billion years, we will pass by or through each other. The gravitational attraction should be strong enough that we will start orbiting closer and closer. In 5 billion years the two galaxies probably will have merged.

What is the biggest challenge that you faced as a female scientist?

Child care. I have four children, and my husband and I were devoted to them all. I worked for almost all of my early career as a part-time person so that I could be home at 3 o'clock, and that was after they were all in school. I did a lot of my work at home. But when I was home, the kids didn't really care what I was doing, so I sat at the dining room table and worked.

Do you think there is life elsewhere in the universe?

I think it's impossible for there not to be. We know the laws of physics are virtually the same all over the universe. That was essentially learned by Cecilia Payne-Gaposchkin in her 1925 thesis, which no one would believe. She discovered that stars are mostly hydrogen and that they are all pretty much the same. There are 200 billion stars in our galaxy, and there are billions of galaxies. I find it impossible to believe our solar system is unique.

If you could visit another galaxy, where would you go?

I'd go to Andromeda so I could look back at our galaxy. I expect I'd see a beautiful spiral with a central bright bulge and dust lanes outlining the arms. The trip would be fun, because you'd have to move through our galaxy to get there. I'd make the person taking me go close to the center—but not the exact center, because then we might get swept into a black hole.

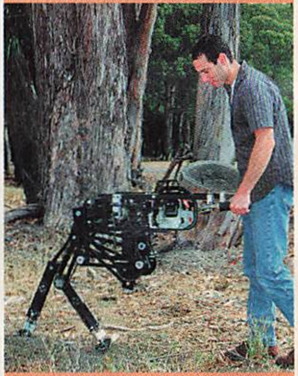
An extended version of this interview is available at www.discover.com.

PHOTOGRAPH BY SASHA BEZZUBOV

FOLLOW-UP:

The Walking Wheelbarrow

HOMAYOON KAZEROONI, A ROBOTICIST at the University of California at Berkeley, is developing powered suits that could aid tomorrow's soldiers (see *Discover,* February 2002, page 25). But he is also working on broader applications for the technology. One of his latest projects is a wheelbarrow with legs. The walking machine can clomp along carrying a 100-pound load while a person follows behind, moving the handles to balance and steer. Kazerooni kept the device simple so it could be robust and inexpensive, around $10,000. A lawn-mower engine powers it along at the pace of a brisk walk. The robot's adjustable gait can travel over rough ground, or up and down staircases. Those talents could make it more versatile than wheeled vehicles for navigating construction sites and disaster areas. "Suppose you're taking an oxygen machine with you. After the machine walks it to the scene, you can use the engine as a source of power," Kazerooni says. He thinks he could build a commercial version in about a year. *—Fenella Saunders*



PHOTOGRAPH: RIGHT, COURTESY OF HOMAYOON KAZEROONI/UNIVERSITY OF CALIFORNIA AT BERKELEY.

> 'Our entire universe may be just one element—one atom, as it were—in an infinite ensemble: a cosmic archipelago'
>
> *—Martin Rees*

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Ludwig van Beethoven.
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by diane martindale

Laser beams make a play to replace the scalpel, the dental drill, and the X ray

Dentistry by Laser Light

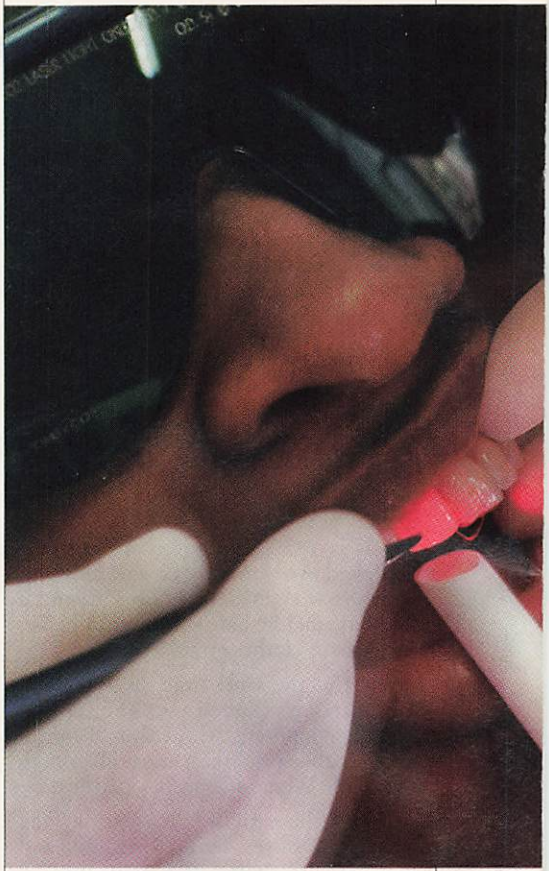
WHEN DENTIST RICHARD HANSEN GOES AFTER A CAVITY OR CLEANS A ROOT CANAL, HIS patients barely hear a thing. Instead of a whiny turbine drill, he uses a flash of laser light to blast away bits of dentin and enamel. Hansen, director of the Center for Advanced Dentistry in Fullerton, California, is convinced that the laser is the dental tool of the future—precise, inherently sterile, less painful, and perhaps less damaging to teeth. Above all, he says, it puts the person in the chair at ease: "What patients like most, of course, is that the laser is silent."

For now, this is still a rare luxury. Just 3.5 percent of the 7,553 dentists recently surveyed by the American Dental Association use lasers for surgical procedures. The steep cost and limited applications of early dental lasers have left many of them skeptical. But the tide is turning, as designs have improved and the Food and Drug Administration has certified lasers for more applications. In 1990 the agency allowed laser cutting of soft tissue such as gums. In 1997 the FDA approved lasers that remove tooth decay and earlier this year gave the thumbs up to laser treatments for root canals and other hard-tissue procedures. Meanwhile, engineers are striving to transform the laser into an all-purpose dental tool, useful for everything from treating gum disease to finding cavities before they surface.

Still, lasers require a hefty investment in equipment and training. Biolase Technology of San Clemente, California, the largest manufacturer of dental lasers in the United States, charges $49,900 for its top-of-the-line Waterlase system. That's a tough sell in a market where most dentists are accustomed to working with drills that use $1.50 tungsten-carbide bits. To make matters worse, lasers suitable for cutting gums are generally not useful for nicking away at cavities, and vice versa, because of the physics of how lasers do their job.

A dental laser shines a powerful beam through a fiber-optic cable connected to a hand piece resembling a standard drill. The beam emerges from the tip, shining onto the tooth or gums. Water molecules there absorb the energy from the beam and convert it into heat that cuts or abrades. But the best way to impart energy to the water molecules depends on the type of tissue. The infrared beam from an erbium laser is absorbed efficiently by the tooth but poorly by the gums. The blue-green light of an argon laser reacts more efficiently with hemoglobin, so it cuts gums effectively and helps halt bleeding. Different jobs, therefore, call for different lasers.

Biolase has already developed one solution. The company's Waterlase machine does not shoot a laser directly onto the tooth or gums. Instead, the beam energizes a spray of water droplets, which blasts the surface and scours away diseased or decayed tissue. This technique addresses concerns that shining a laser directly on a tooth can generate enough heat to harm the enamel. Earlier this year the FDA sanctioned Waterlase for both soft- and hard-tissue work in root canals and jaw surgery. Keith Murray, a laser physicist at NASA's Langley Research Center in Hampton, Virginia, is working on a more elegant approach. He has designed an adjustable laser that can switch instantly between soft-tissue and hard-tissue wavelengths.

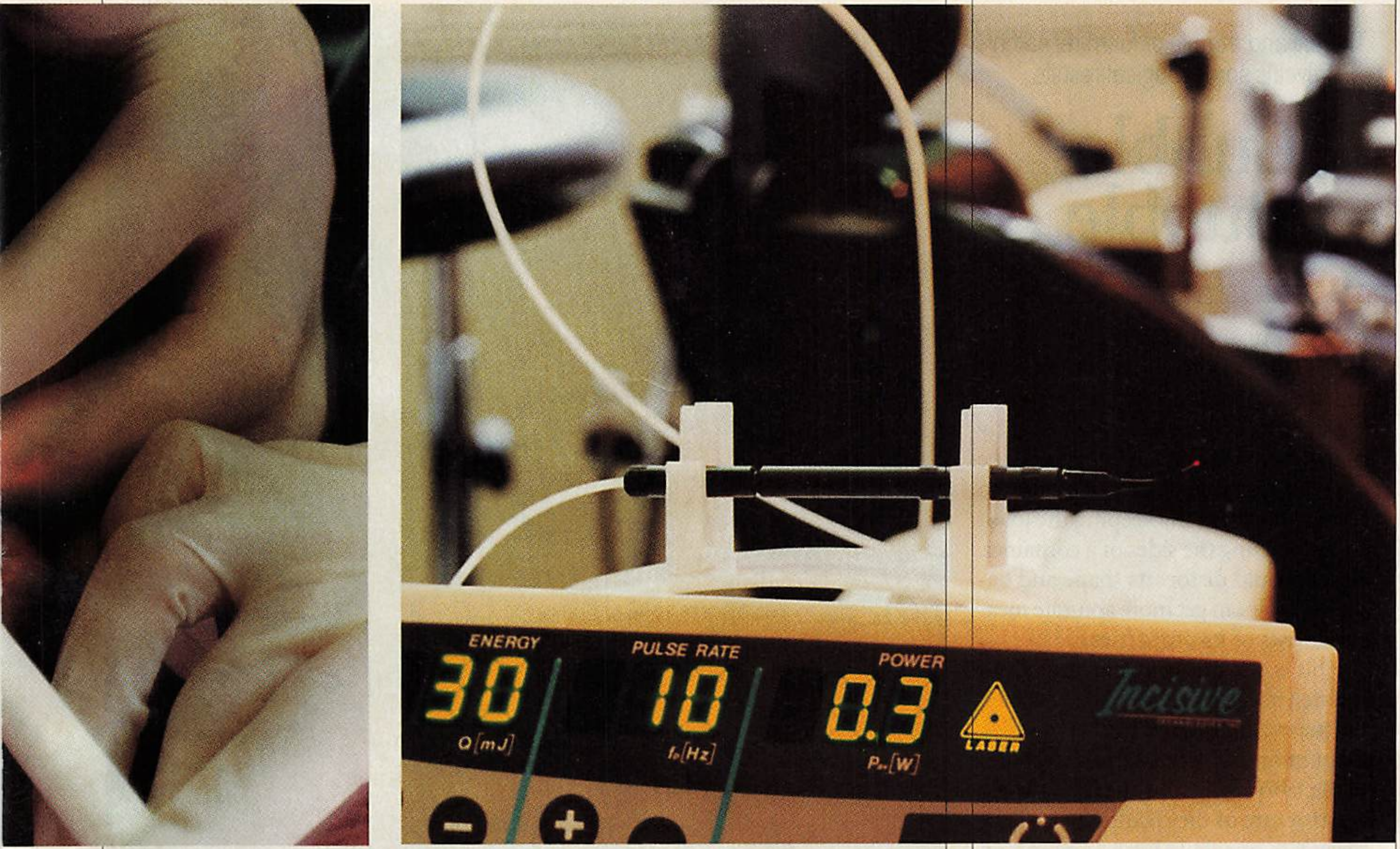


Other researchers are bypassing the difficulties of laser drilling and concentrating on soft-tissue applications, where lasers offer some significant benefits. Lasers cauterize incisions, reducing bleeding and infection, sealing off nerve endings, and minimizing postoperative pain. Brian Wilson, a biophysicist at the University of Toronto, is expanding the repertoire of soft-tissue lasers to include applications for severe gum disease, which affects 5 to 20 percent of all Americans, especially teenagers and young adults.

Normally, dentists clean out infections between the teeth and gums by making an incision and inserting pellets of antibiotics. Instead, Wilson proposes using lasers and other light sources for photodynamic therapy, originally developed in cancer treatments. The dentist would inject the infected parts of the gums with a dye molecule that remains inert until illuminated with a laser or other light source. Once energized, the dye forms singlet oxygen, a reactive molecule that kills bacteria.

While patients appreciate the quiet, lasers have other appealing qualities to dentists. The intense beams of light sterilize tissue as they go. They can speed up tooth whitening. And lasers help make dentistry more precise, for instance, by allowing very controlled tooth bonding.

PHOTOGRAPH BY AMY ECKERT



Alan Goldstein, a dentist in New York City, uses a pulsed laser (left) to perform soft-tissue work such as reshaping gums. A guiding red laser beam marks the invisible surgical beam. Digital controls (right) regulate the power and frequency of each pulse.

"This process does away with complicated, painful surgery. Also, the dye is not an antibiotic, so I don't believe bacteria will become resistant," Wilson says. In a recent lab test, photodynamic therapy killed 99.9 percent of *Pseudomonas gingivalis*—one of the bacteria that cause gingivitis—in 10 minutes. Clinical trials are scheduled for later this year.

Lasers might also be useful for diagnoses. "With fluoride treatments and other improvements, we rarely see big gaping holes in people's teeth," says Andreas Mandelis, an applied physicist working on lasers at the University of Toronto. These days, most patients show up having only tiny pits in their tooth enamel. Dentists can halt these nascent caries with a polymer bonding agent, but only if they can spot the damage. In 2000, KaVo, a medical-imaging company in Germany, began selling a simple decay detector in the United States that supplements conventional X rays and the dentist's sharp explorer probe. Called Diagnodent, the $2,800 machine illuminates the tooth with a low-power red laser and measures whether the enamel glows, or luminesces, in response—a sign of bacterial degradation. About 5,500 units are in use in this country.

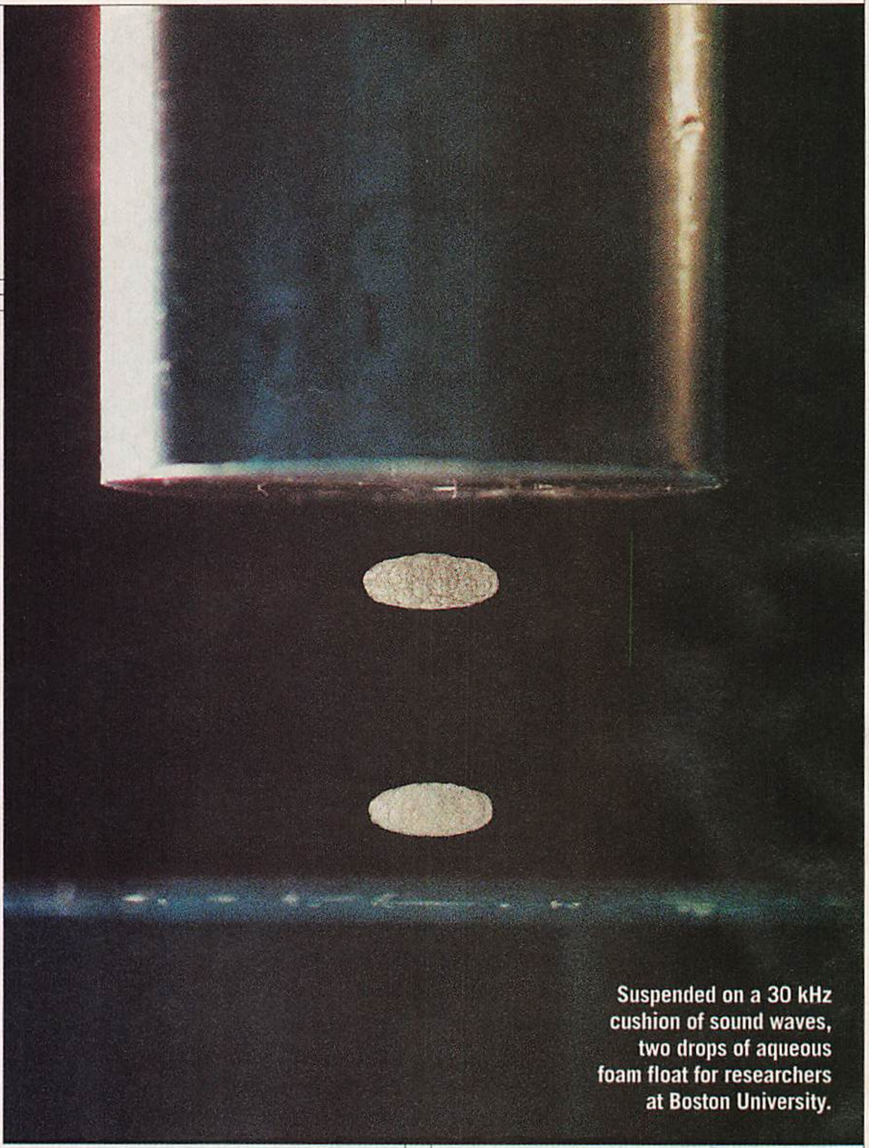
Diagnodent can distinguish between stains and incipient cavities, but it cannot locate decay more than about one-tenth of an inch into the tooth, because laser light is easily scattered. Mandelis and Toronto dentist Stephen Abrams are developing a more effective laser-luminescence cavity detector by looking at thermal effects as well. Their technique uses a longer-wavelength infrared laser beam, which heats the tooth in addition to making it glow. Heat does not scatter as readily as light, so the thermal energy can penetrate through the enamel, exposing changes in composition. An infrared detector measures how the heat travels through the tooth while a light sensor picks up the fluorescent signal. The combined information allows a three-dimensional look at the tooth. "It is more accurate than dental X rays, without the side effects," Abrams says. Mandelis's group has experimented on only extracted teeth, but he expects a commercial device to be available in about five years.

What will the world of tooth care look like then? Some dentists wonder how much will have changed. "Lasers are not the panacea that has been presented in the media. It's a new and potentially promising technology that will need several years of research and improvements before I'll feel confident using it on my patients," says Jerry Gordon, a dentist in Bensalem, Pennsylvania. But Richard Hansen thinks laser precision will spark a revolution. "What we've done in the last few years with lasers is to prevent the need for root canals," he says. "Soon we may be able to eliminate most adult dentistry entirely." ☒

by jennifer ouellette

The toil and trouble of foam research reveals some magical results

Bubble, Bubble


Suspended on a 30 kHz cushion of sound waves, two drops of aqueous foam float for researchers at Boston University.

ON ANY GIVEN DAY VISITORS TO GLYNN Holt's laboratory at Boston University are likely to see a peculiar sight: a single drop of foam suspended as if by magic in midair. What they can't see are the acoustic waves that Holt uses to levitate the foam. By keeping the foam from touching the sides of a container, which would distort its shape and behavior, Holt can get more accurate measurements of its properties.

Holt is one of a growing number of researchers intrigued by foams and their unique qualities. Foams exist at all scales, from quantum gravitational bubbles in the fabric of space-time to the galactic structure of the cosmos itself. They permeate our daily lives, popping up in popular foods and beverages, personal grooming products, household soaps, and works of art.

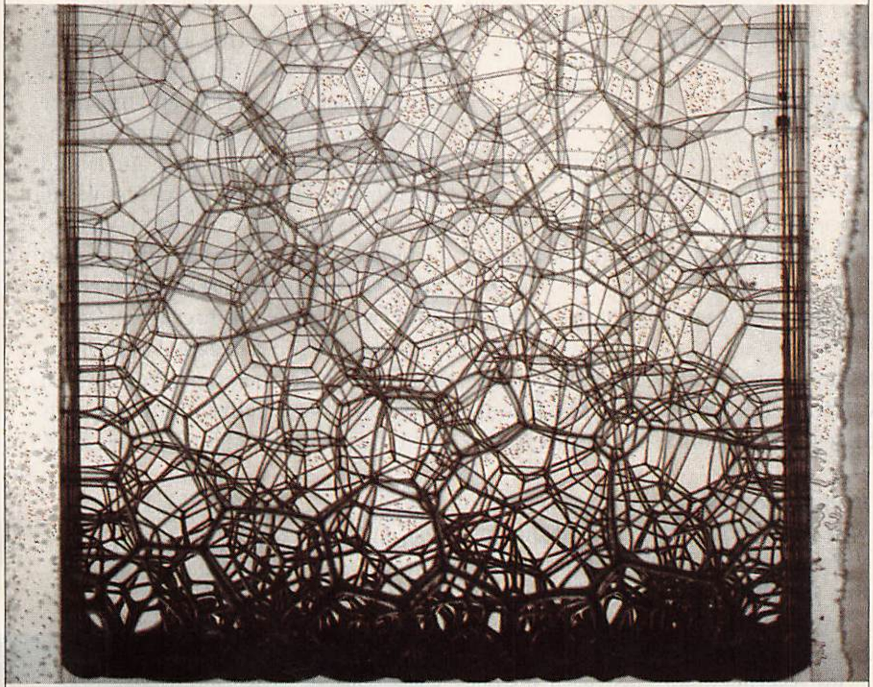
Sidney Perkowitz, professor of physics at Emory University and the author of *Universal Foam,* cites foams as examples of soft matter: They don't flow freely like a true liquid, but neither are they a crystalline solid like a diamond. "We're very good at explaining hard matter like crystals; the entire semiconductor industry is based on them," he says. "Soft matter seems to tell us a lot more about nature and biology." Although particle physicists believe that a grand unified theory will rest on a more complete understanding of elementary particles, condensed-matter physicists think that the key lies in deciphering how physical laws evolve in complex systems like foam.

The origins and macrostructure of foams are well understood. "We're not discovering foam; it has existed for a very long time," says Douglas Durian, a physicist at the University of California at Los Angeles. "We're just trying to figure out how it works." Most foams contain a *surfactant* (short for "surface active agent"), a collection of complex molecules that aggregate at the bubbles' surfaces. A surfactant—fats or proteins in edible foams, chemical additives in shaving cream—prevents a foam from collapsing under surface tension by keeping the bubbles separate and by repelling water from their surfaces, which keeps them from popping. Milk fat, which makes up 20 percent of heavy cream, acts as the surfactant in whipped cream. In nondairy varieties, milk fat is replaced by vegetable oil, which has an even higher fat content than cream.

Scientists know a great deal about the individual bubbles in such foams and how they "talk" to one another through simple friction. But when many bubbles clump together to form a foam, the resulting material exhibits a host of unexpected properties and behaviors. Liquid foams, for instance, are composed of roughly 95 percent gas and 5 percent liquid, yet they tend to be far more rigid than their components. This is due to

Shaving gels are supersaturated with bubbles that grow by diffusion, sped up by the hand's agitation. The same concept underlies a portable neutron detector invented in the early 1980s. Its foam is triggered by ionizing radiation, which makes bubbles expand and noisily pop.

PHOTOGRAPH BY FELICE FRANKEL



Bubbles in a soapy froth, held in a Plexiglas container one inch wide, clump in complex geometrical formations first conjectured by England's Lord Kelvin in the 19th century.

PHOTOGRAPH COURTESY OF JOHN SULLIVAN, MATT FETTERMAN, AND SIGGI THORODDSEN.

a phenomenon called jamming. Because the bubbles are so tightly packed, when a foam is pressed down, the bubbles can't hop around one another. The more the bubbles are jammed together, the greater the pressure inside them grows—and, consequently, the more they take on the characteristics of a solid.

Then there's the matter of shape. A foam's properties are largely determined by the shape of its individual bubbles, but the exact nature of that shape is one of the oldest mathematical conundrums. In the 19th century, England's Lord Kelvin, of absolute-zero fame, came up with a shape eponymously dubbed Lord Kelvin's cell—a complex figure with six square and eight hexagonal faces that Perkowitz describes as "a demented soccer ball." In 1994 Denis Weaire and Robert Phelan, of Trinity College, Dublin, used a computer program to find a foam with even more efficiently packed bubbles. Their Weaire-Phelan structure, which comprises two different shapes of equal volumes, is an improvement on Kelvin's cells, but it has not yet been proven whether this is the most economical structure possible.

The biggest challenge facing sudsy scientists is to create predictive models of foam rheology, that is, the way it deforms and flows over time. As foams age, gravity drains their liquid downward, and smaller bubbles are absorbed by larger ones, a process called coarsening. But until quite recently our understanding of this process has been limited by the inherent difficulties of studying such an ephemeral material. Foams are fragile, and they usually have to be confined to a glass container to be studied, which itself alters their behavior.

For Holt, who was trained by NASA as a payload specialist for spaceflights, the solution was simply a matter of defying gravity. By using sound waves to suspend a drop of foam, he can manipulate its position and squeeze the bubbles to make them oscillate. "This is not simply attraction force on the surface of the drop," he says. "The sound propagates within the foam, which is how we're able to levitate it. So we can get a sense of how it responds as we manipulate it." A video camera hooked up to a monitor records the complex vibrations, which Holt then analyzes to get a better grasp of the foam's mechanical properties—most notably the point at which it begins to act more like a solid.

Douglas Durian has taken a different approach. In 1990, while still with Exxon, he placed some shaving cream in a small glass cell, shone a laser beam through one end, and measured the amount of light that emerged through the opposite side—a technique known as diffusing wave spectroscopy. Over time, he found, the light's intensity fluctuated as the bubbles both consolidated and rapidly shifted position. As the foam shifted, its internal stresses grew, until groups of tightly packed bubbles suddenly snapped from one configuration to another like a slow-motion avalanche. If Durian applied enough pressure, the bubbles would rearrange constantly, flowing like a liquid.

It is this wide range of unique mechanical properties—from elastic solid to viscous fluid—that makes foams so useful for everyday applications. Most recently, a new anti-terrorism foam was used to decontaminate congressional office buildings and mail rooms in Washington, D.C. Developed at Sandia National Laboratories, the foam neutralizes toxic chemical and biological agents such as anthrax and sarin nerve gas within minutes. The foam, sprayed from handheld canisters, expands to about 100 times its liquid volume as air is drawn into the spray. It fills crevices and other elusive hiding places, then collapses back to its compact liquid state a few hours later.

The foam neutralizes toxic substances in much the same way a detergent removes stains from clothing. Its surfactants and mild oxidizing substances digest the chemical agent, seeking out the phosphate or sulfide bonds holding the molecules together and chopping them into bits. Sandia researchers aren't entirely sure how the foam kills bacterial spores, but they think the surfactants poke holes in the spores' protein armor, allowing the oxidizing agents to attack the genetic materials inside.

As practical as foams can be, their true appeal to physicists lies in their unique behavior. Ultimately, foam research may help explain the structure of plant cells and the ways in which biological systems emerge and evolve—subjects as complex as foam itself. ☒

by claire panosian dunavan

A fearsome infection spoils a honeymoon

Bad Fever

THE MESSAGE WAS BRIEF BUT URGENT: "HONEYMOONER ARRIVING TONIGHT FROM TAHITI. Has fever, headache, hemorrhagic rash. Will take ambulance to our emergency room. Can you meet her there?"

That year, I took care of three returning newlyweds with the same tropical woe—but none as sick as Susie Gold.

Susie and her fiancé, Jeff, had resolved to have a one-of-a-kind wedding in the South Pacific, where they would exchange vows under a cabana of palm fronds. Everything went off without a hitch, but five days later Susie developed teeth-chattering chills. Her muscles felt sore and bruised. At first she downplayed her symptoms, figuring she was wiped out from the wedding or fighting a bug she had picked up on the plane. It would pass.

Sure enough, a day later, she was better. She and Jeff resumed snorkeling and strolling along the beach, their happiness marred only by sunburned noses and mosquito bites.

The next morning Susie's head and eyeballs ached furiously, her brow was hot, and her legs sported a rash that looked like purple shooting stars. Her biggest scare came after flossing her teeth. She tasted salt, looked in the mirror, and saw bright red blood.

Jeff called Susie's dad, a psychiatrist. He listened to Susie's symptoms, then rang off to consult with the family internist. Thirty minutes later he was back on the line.

"Jeff, you've got to bring Susie back. Don't worry; I've arranged everything. Once you land in Los Angeles, an ambulance will take her straight to the university hospital."

If Dr. Gold had actually spoken to me before Susie boarded her plane, I probably would have vetoed the daylong wait before she was seen by a doctor. To an infectious-diseases specialist, her constellation of fever, headache, and pinpoint bleeding in the skin indicates meningococcemia until proven otherwise. Meningococci are bacteria that invade the blood and the meninges that line the brain. A 12-hour delay in receiving antibiotics can be the difference between life and death.

But deep in my gut, I worried that Susie might have another misery that can mimic meningococcemia. Starting in the 1980s, dengue—a mosquito-borne virus that dogged Allied and Japanese troops during World War II—made a stunning comeback in the Pacific, Southeast Asia, and the Caribbean. Like meningococcal infection, dengue also causes fever, headache, and hemorrhagic rash.

A small, black-and-white mosquito, *Aedes aegypti,* is dengue's main vector. It loves to breed in water-filled crockery, cisterns, trash containers, and spare tires that surround human habitation in the tropics. That's a lucky coincidence for an insect whose survival depends upon blood meals. In turn, the blood-borne dengue virus profits from its vector's feeding habits. With the slightest provocation, the female *Aedes* stops her blood meal, only moments later to resume probing and siphoning the same or another nearby victim. Thus, a lone mosquito carrying dengue from a previous host can spread the virus to multiple recipients.

After an *Aedes* loaded with dengue inoculates its victim, illness begins within seven days. Although symptoms range widely, fever, chills, and headache often herald the attack, along with facial flushing, swollen glands, and a mild sore throat. Then comes a deceptive lull before dengue's encore fever arrives. This later stage features an array of skin rashes as well as dengue's famous aches, otherwise known as breakbone fever.

Dengue's most dreaded complications are hemorrhage and shock, which typically strike children and adolescents battling the infection for a second time.

Below: A protein shell surrounds and protects the genetic material of the dengue virus. Researchers recently determined the shell's structure.

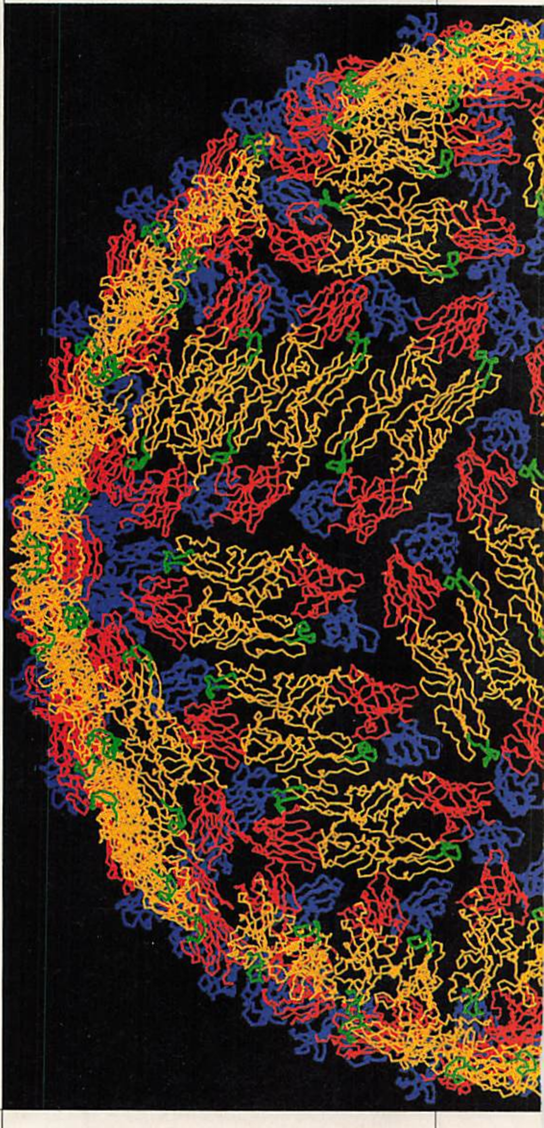


IMAGE COURTESY OF MICHAEL G. ROSSMANN/RICHARD KUHN/PURDUE UNIVERSITY.

Each year more than 50 million people are infected with this virus, one of a few carried by the *Aedes aegypti* mosquito. The virus has four strains, and second infections with a different strain can prove particularly dangerous. If left untreated, patients with severe infections may die.

During a second bout of dengue, old antibodies are thought to bind to the new virus, but they fail to clear it because of changes in the new infecting virus. Instead, antibody-virus complexes are engulfed by watchdog cells called macrophages. During severe infections, macrophages can release chemical signals that cause capillaries to leak, which results in bleeding and, at times, drastic depletion of plasma volume.

Still, Susie's case didn't stack up perfectly for dengue because her bleeding didn't fit with a first-time infection. A true diagnosis would be tricky: There's no easy test for dengue.

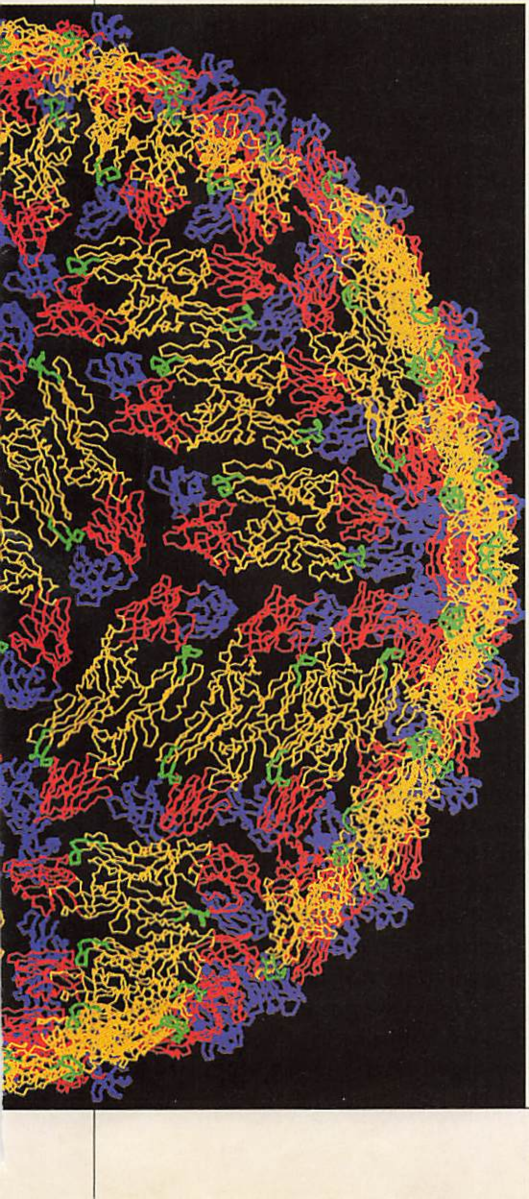
Eight hours later I got a call on my pager from our emergency room. Susie had arrived.

I hurried to the cubicle where she lay pale and sweaty but lucid. Her blood pressure was low and her pulse was high. She had bleeding gums and a sprinkling of hemorrhagic dots on all four extremities, just as she had described. Otherwise, the physical exam revealed only a few lentil-size lymph nodes and a tender liver edge below the right rib cage.

"She didn't eat a thing on the plane," Jeff said, his voice tinged with worry, "and when she stood up at the end of the flight, she nearly fainted."

Drip, drip, drip: An intravenous set was running saline into Susie's vein at the fastest rate the tubing would allow. Adding fluid would help bring up her blood pressure and prevent her from going into shock.

"Her vascular volume is low," I replied, avoiding the term "shocky," which the ER resident had used to describe the washed-out bride. "Right now she needs lots of fluid. We'll deal with food later."



SUSIE'S CASE DIDN'T STACK UP. A TRUE DIAGNOSIS WOULD BE TRICKY: THERE'S NO EASY TEST FOR THIS DISEASE

I turned to Susie. "Don't worry. It will be rough, but you'll pull through."

At that point I left to review lab tests. Just as expected in a major viral assault, Susie's leukocytes and platelets were low. That meant she was depleted of cells that counter infection and bleeding. At the same time, her liver enzymes were elevated three- to fourfold, corresponding to the swollen, tender edge I felt on exam. Everything fit with dengue, yet nothing was truly diagnostic. Meanwhile, it would take 48 hours before blood cultures were known to be negative for meningococcus.

Sometimes being a purist is a mistake in medicine. Although I was confident that Susie had dengue, a disease for which antibiotics are ineffective, I asked myself: In her shoes, would I want antibiotic treatment until a serious bacterial infection was 100 percent excluded? My answer was yes.

"Let's start ampicillin and ceftriaxone for now," I said to the resident, "but don't forget to order an antibody test for dengue fever. It may take a long time to get the result, but it could be our only proof."

My next stop was the library. All day a vague memory had nagged me. Hadn't I seen a case report describing hemorrhage and shock in first-time dengue? Or was my mind playing tricks on me?

The American Journal of Tropical Medicine and Hygiene came through: "Dengue shock syndrome in an American traveler with primary dengue 3 infection" (March 1987). In the 15 years since that report, with the blossoming of dengue and exotic overseas travel, such cases in tourists are no longer rare. For reasons that are unclear, even these first-time infections can occasionally lead to bleeding and shock.

As for Susie, she spent the next few days in the hospital while her plasma volume restored, her bleeding stopped, her skin hemorrhages cleared, and her lab tests normalized. As expected, her blood cultures remained negative, so we finally shut off her antibiotics 48 hours after admission. Three days later, when she and Jeff were ready to return to the East Coast, the only remnant of her ordeal was depression. Post-dengue blahs, sometimes referred to as neurasthenia, were well known to British colonials. I reassured Susie that her mood was normal and would gradually improve on its own. The following week her dengue antibody sent from the emergency room finally came back positive. ☒

The case described in Vital Signs is based on a true story. Some details have been changed to protect the patient's privacy.

THE DOCTOR IS IN

Claire Panosian Dunavan is an infectious-diseases specialist at the UCLA School of Medicine. She also writes for a monthly column, "The Doctor Files," in the *Los Angeles Times*. Dengue is raging in Brazil, says Dunavan, and Easter Island reported its first case of dengue on March 13. A dozen more cases have been confirmed.

by karen wright

Even in a small world, there's room for disagreement

Six Degrees of Speculation

YOU PROBABLY DON'T KNOW JUDITH KLEINFELD. SHE'S A PSYCHOLOGIST AT THE UNIVERSITY of Alaska in Fairbanks, and you can contact her by calling the university switchboard or finding her e-mail address online. But could you get to her through some extension of your own social network—by mailing a letter for her to a friend who might know someone who knows someone who knows her?

Who cares?

Judith Kleinfeld does, for starters. She's part of a growing cadre of scientists reviving the so-called small-world problem, a social-cum-mathematical conundrum formulated in the last century to characterize the interwoven webs of acquaintance among friends, neighbors, colleagues, and kin. In the mid-1960s the legendary social psychologist Stanley Milgram asked randomly selected citizens of Kansas and Nebraska to try to connect with social "targets" in Massachusetts by mailing letters to likely intermediaries. The average number of links between strangers turned out to be surprisingly small. Milgram claimed we're all connected, on average, by half a dozen interpersonal avenues—a numinous network popularized by the phrase "six degrees of separation."

Now some mathematicians say the dynamics of such networks can describe a host of natural and technological systems. But Kleinfeld, who has reviewed the Milgram archive at Yale University, says the small world may have no basis in fact. "It's not a robust social-science finding," she asserts. "It's a very odd one that has never been replicated."

The original small-world question was posed in the 1960s by political scientist Ithiel de Sola Pool of the Massachusetts Institute of Technology and IBM mathematician Manfred Kochen. How many acquaintances, they wondered, connect any two people chosen at random? Kochen and Pool's calculations put the average number at three. Milgram devised an experiment to test that surprising prediction. He recruited volunteer "starters" in Kansas and Nebraska from mailing lists and newspaper ads and told them the name, address, and occupation of a target in Massachusetts. He asked the starters to forward a document to someone they knew on a first-name basis who might be able to reach the target. In a 1967 report of his results, Milgram described how one folder had found its way to the wife of a divinity student in just four days and three steps: from a Kansas wheat farmer to an Episcopal minister, from the minister to a colleague in Cambridge, and thence to the divinity student's wife. In that case, Milgram wrote, "The number of intermediate links between starting person and target person amounted to two!" The average number of intermediates was five—six steps, in other words, connected Milgram's distant strangers.

As a graduate student in the late 1960s at Harvard, where Milgram worked from 1963 to 1967, Kleinfeld had known of Milgram's studies. But it wasn't until the 1990s that she decided to try to repeat his study as an exercise for her graduate students. When she went to the Yale archives to find out more about his methods, Kleinfeld saw that the rates of completion in Milgram's studies were lower than she'd realized. In the main study, using almost 300 starters, only 29 percent of the documents reached a Boston stockbroker—and 100 of the Nebraska starters owned blue-chip stocks. In a pilot study—the one that yielded the anecdote of the divinity student's wife—just 5 percent of 60 documents reached the target, and they passed through an average of eight people. And Kleinfeld couldn't find any exact replications of Milgram's experiments in the literature.

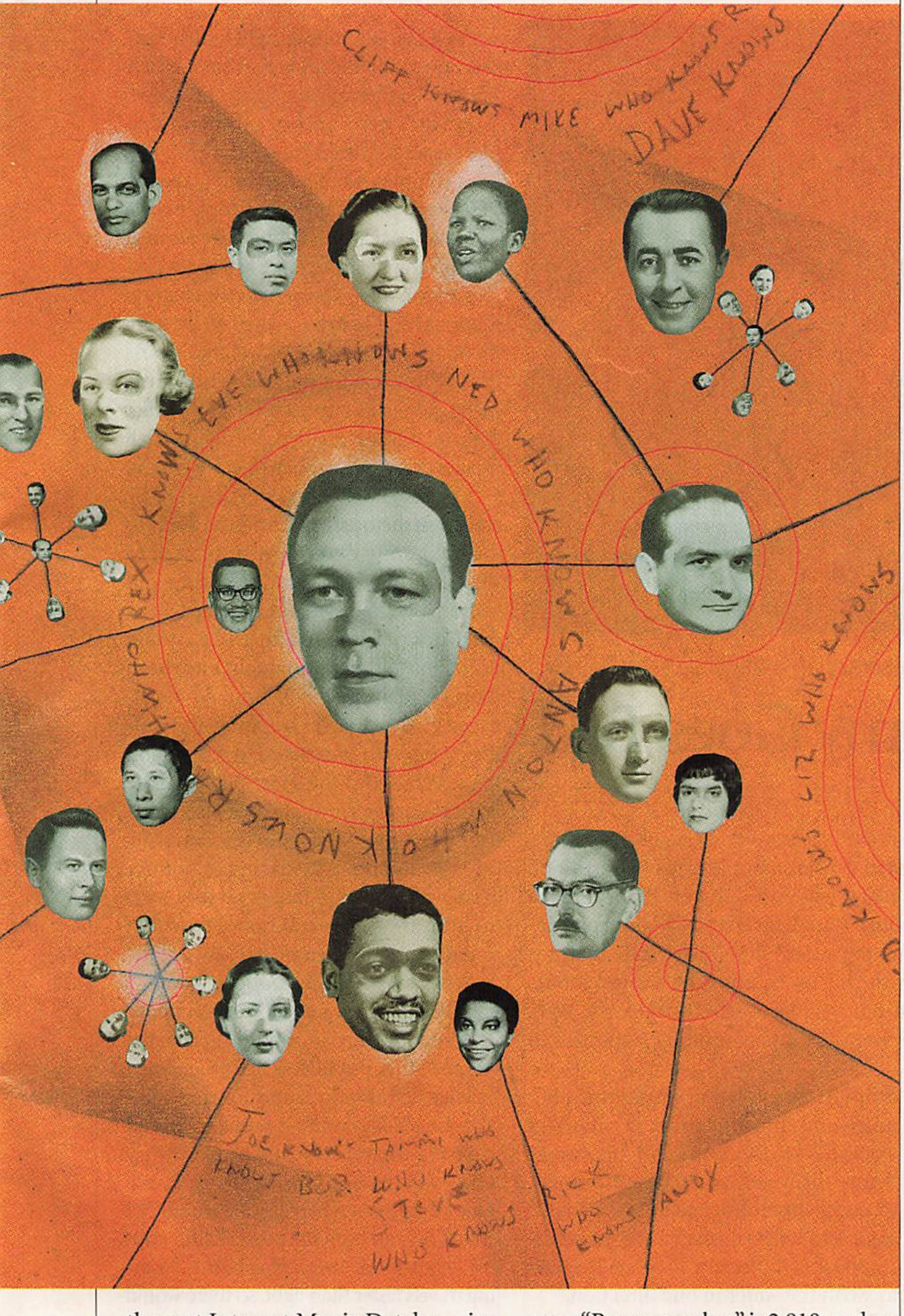
"I was really upset and discouraged," she says. "I thought, 'Oh, Stanley, how could you do this?'"

Milgram, whose controversial studies of obedience to authority earned him celebrity, died in 1984. But his small-world concept still has its defenders. "It's a solid phenomenon," maintains Thomas Blass, a Milgram scholar at the University of Maryland, Baltimore County, who says Kleinfeld's criticism is overblown. Many investigators don't report the results of pilot studies, Blass says. And Milgram's low completion rates don't necessarily mean that his participants hit dead ends. "It's as likely that the low completion rates are because people just lost interest. If that's the case, it doesn't damage the small-world phenomenon."

Support for Milgram's idea has come from another camp as well. In the mid-1990s, mathematician Steve Strogatz of Cornell University and his graduate student Duncan Watts began constructing theoretical models that explained how millions of people could be linked by relatively short social routes. Watts and Strogatz's models show that the members of a big network can be connected by short paths if the network comprises clusters of close associates joined by occasional, far-reaching links—"random" elements in otherwise structured groups.

To test whether such networks actually exist, Watts consulted one of the few impeccably documented social circles known to science: the parlor game Six Degrees of Kevin Bacon. The game, housed online by the Oracle of Bacon at Virginia Web site and supported by

To help understand the small-world phenomenon, Milgram likened it to a form of geometric progression. Each degree of separation in the social world amplifies a person's contacts not by just one person but by hundreds of acquaintances belonging to that contact.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the vast Internet Movie Database, involves finding the shortest route between any given thespian and actor Kevin Bacon. Links are forged by appearing in a movie with Bacon, or with someone who has appeared with Bacon, or with someone who has appeared with someone who has appeared with Bacon, and so on. Among the hundreds of thousands of actors living and dead, the average "Bacon number" is 2.918, and no actor has been found to be more than 10 degrees of separation from Bacon.

Watts learned that the Bacon network conforms to his models of a small world: Groups of closely associated actors are joined by random "linchpins" that link far-flung clusters. Linchpin actors may have long careers, like *Green Acres*'s Eddie Albert, thus joining clusters in time. They may link the films of different cultures, as Bruce Lee does. Or they may span genres, like Nicolas Cage (comedy and suspense). There's reason to believe that ordinary social networks operate according to similar principles, says Watts. And he's found the same kind of connectivity in systems ranging from the neural wiring of a nematode to the electrical power grid of the western United States. Small-world networks may also describe the spread of disease, fads, and social movements.

"Even just a little bit of randomness in any network is going to generate short paths between different nodes," says Watts. "Milgram showed that people can actually find those paths—and that's a different sort of problem. The models we developed to show that these short paths actually exist don't explain how you can find them."

How people recognize the routes to their distant affiliates is the next big small-world question. Computer scientist Jon Kleinberg at Cornell has proposed an algorithm to explain it (although Milgram himself conceded that "there is nothing more alien to mathematically untutored intuition than this form of thinking"). Watts is trying to trace both the reasoning and the routes through an e-mail replication of Milgram's experiment. He's got 50,000 participants so far, with targets in India, Europe, Indonesia, and Australia as well as the United States. "We've already had some globe-crossing chains—from Sydney to Siberia in four links," he says. "It can be done."

Kleinfeld thinks an e-mail experiment misses the point, because computers link people who already have a lot in common—such as income and education. "I think scientists live in a small world," says Kleinfeld. "People who are low-income or minorities aren't connected."

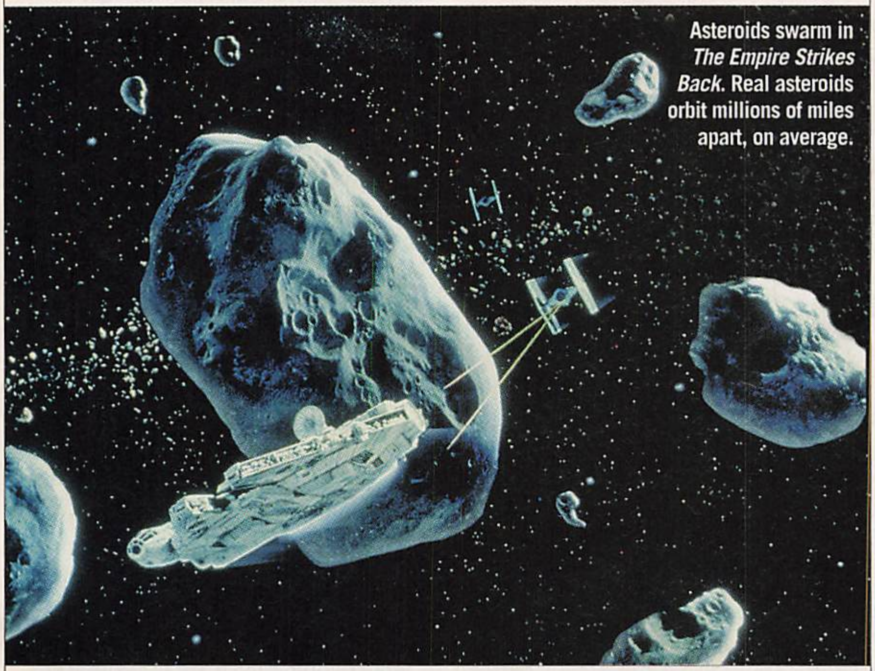
Watts concedes that the e-mail network is a practical compromise. "In terms of getting very large numbers of people [to participate], nothing can beat the Web," he says.

Blass gives Milgram the final word. "Milgram would be very happy about it," he claims, "because he was one of the first people to appreciate the communicative value of PCs." ☒

ILLUSTRATION BY DAVID PLUNKERT

SKY LIGHTS

by bob berman


Asteroids swarm in *The Empire Strikes Back*. Real asteroids orbit millions of miles apart, on average.

Why are media science stories still crazy after all these years?

When Astronomy Goes Bad

EVEN AS RESEARCHERS REPORT ONE AMAZING DISCOVERY AFTER ANOTHER, MEDIA DEPICTIONS of astronomy seem stuck in a state of arrested development. Many scientists look at the endless misconceptions that fill the airwaves and sigh, but Philip Plait, a NASA consultant and astronomer at Sonoma State University in California, decided to do something about it. After watching a local newscaster state that it is possible to balance an egg on its end only during an equinox, he wrote a rebuttal and posted it in what was then, in 1994, a novel place—the World Wide Web. Four years later he launched badastronomy.com, a site compiling responses to celestial misinformation. Now he has published a companion book, *Bad Astronomy*, that uses scientific goofs to teach people how the world really works.

The media's astronomy errors fall into three broad categories: silly, sloppy, and malicious. Egg balancing clearly falls in the first group. It takes only a moment's thinking to realize gravity is no different during the equinoxes than at any other time. The myth that flushing toilets and draining sinks swirl the opposite way in the Southern Hemisphere is another example of silly science. Pseudo-experts claim Earth's rotation causes this phenomenon, but the effect is tiny: You would have to let a sink sit for three weeks before the water would be still enough to reveal any influence of our planet's spin. And toilets flush in a consistent direction merely because they are designed to swish the water in one direction.

Sloppy mistakes result from unfamiliarity with the basic workings of science. Plait has complained about reporters who refer to the giant "lens" of the Hubble Space Telescope. Like all large telescopes, Hubble collects light with a mirror. Sure enough, during the recent NASA mission to upgrade the Space Telescope, a network news anchor promised that the upgrade would "make the Hubble's lens 10 times more powerful." Likewise, reporters often claim that people on the International Space Station have escaped Earth's gravity. In fact, the astronauts experience a full 89 percent as much gravitational pull in orbit as they do on terra firma. The sensation of weightlessness arises because the station is constantly falling along its curved orbit, like a roller coaster taking a steep plunge, which makes everyone on board feel weightless.

The worst offenses, which could be called maliciously bad science, seem to be deliberate deceptions intended to boost ratings. Last year, scientists and astronauts expressed disgust when a Fox network program claimed the Apollo missions to the moon might have been hoaxes. Plait quickly debunked the alleged evidence point by point, and traffic on his Web site soared to 4.5 million page views. But the most powerful rebuttal comes from science itself. Astronomer Tom Murphy of the University of Washington is preparing to bounce a laser off a set of reflectors on the moon to measure the lunar distance to within one-twentieth of an inch. How did the reflectors get there? Apollo astronauts installed them for just such experiments.

Sometimes bad astronomy is all in the name of fun. But Plait, a self-proclaimed science fiction nut, cannot resist deconstructing Hollywood's space fantasies and showing what they would be like if they obeyed the laws of physics. Spaceship engines would not whoosh, stars would not streak by, and even the most skillful pilot could not dodge enemy laser beams. Nothing travels faster than light, so there would be no way to know that a beam was headed your way until it arrived.

Plait isn't out to lecture. His goal is to demonstrate that reality is actually more interesting than make-believe. To understand why you can balance an egg at all, you need to know how a hen's body makes an eggshell—and that's a much better story than the scrambled science any newscaster might create. ☒

The sky appears blue because white sunlight contains a blue component that is bounced around by air molecules. So why is the ocean blue? Many people think it is just a reflection of the sky. In fact, water absorbs sunlight's red wavelengths, leaving more of the blue to reflect off the sea.

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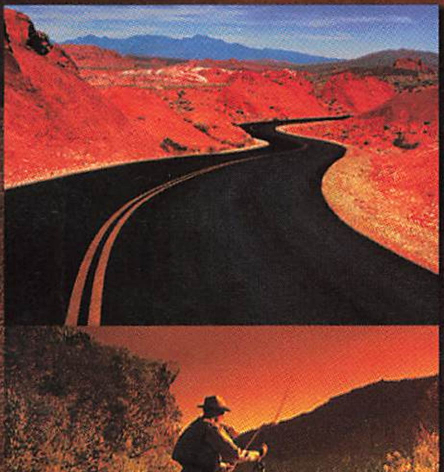

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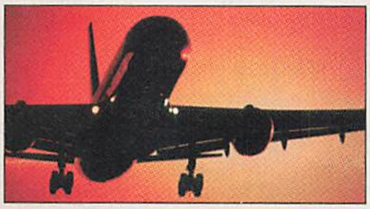

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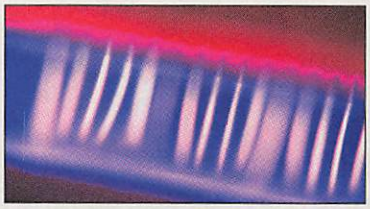

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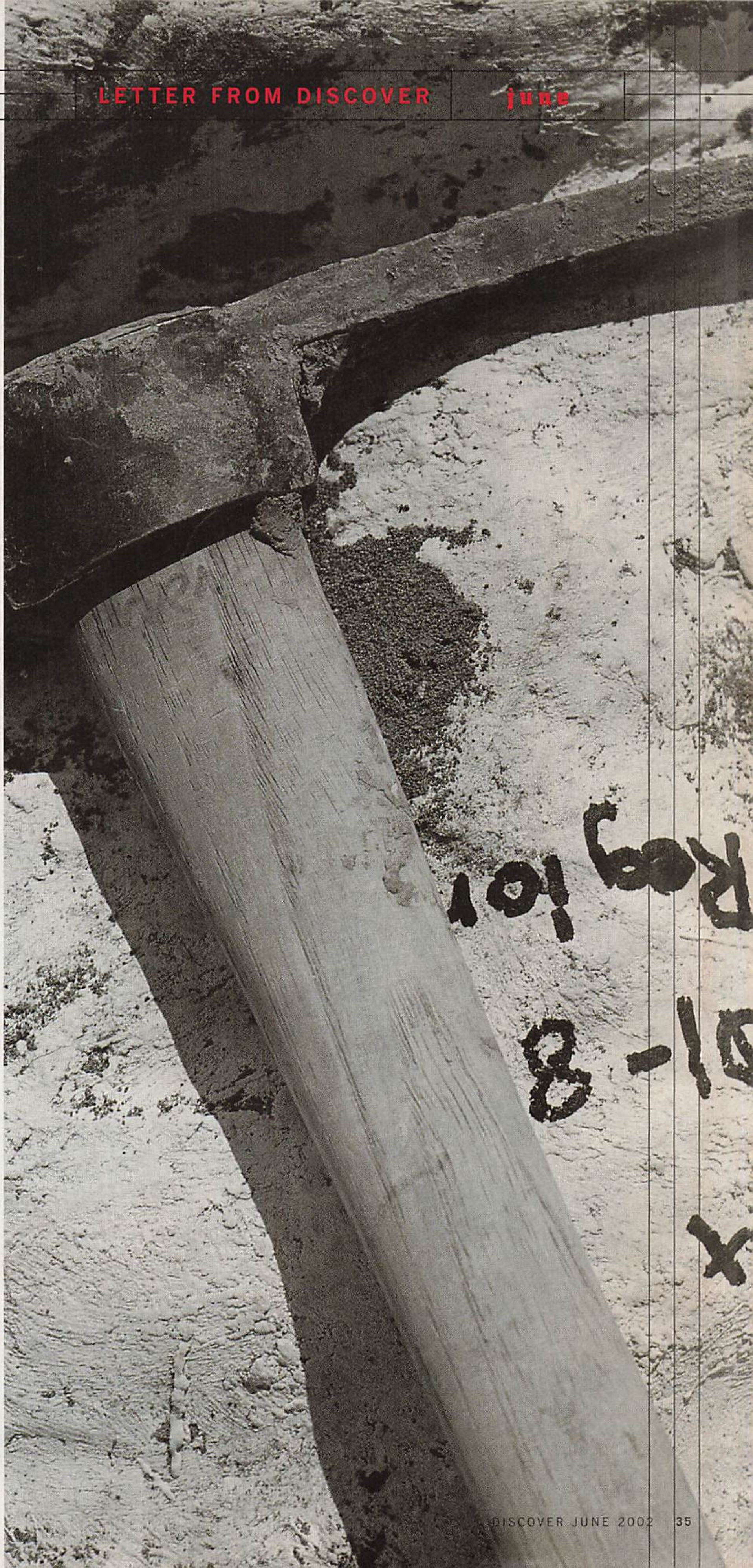
Digging Dinosaurs

WHEN YOU HEAR THE WORD *DINOSAUR,* WHAT image immediately comes to mind? A snarling, hungry *Tyrannosaurus rex*? That mighty carnivore has captured the public imagination to such an extent that a real Jurassic Park without a *T. rex* would be like Coney Island without a roller coaster. The same holds for natural history museums. In 1997 The Field Museum in Chicago shelled out $8,360,000 for Sue, a fossilized *T. rex* named after dino hunter Sue Hendrickson, who found several of its bones popping up from South Dakota dirt in 1990. Why would a museum pay so much for a heap of bones? Because tyrannosaur skeletons are extremely rare. The first one was found only 99 years ago. Until recently, only a half dozen major fossils had been dug up, and most are missing half their bones. Sue's skeleton is about 90 percent complete.

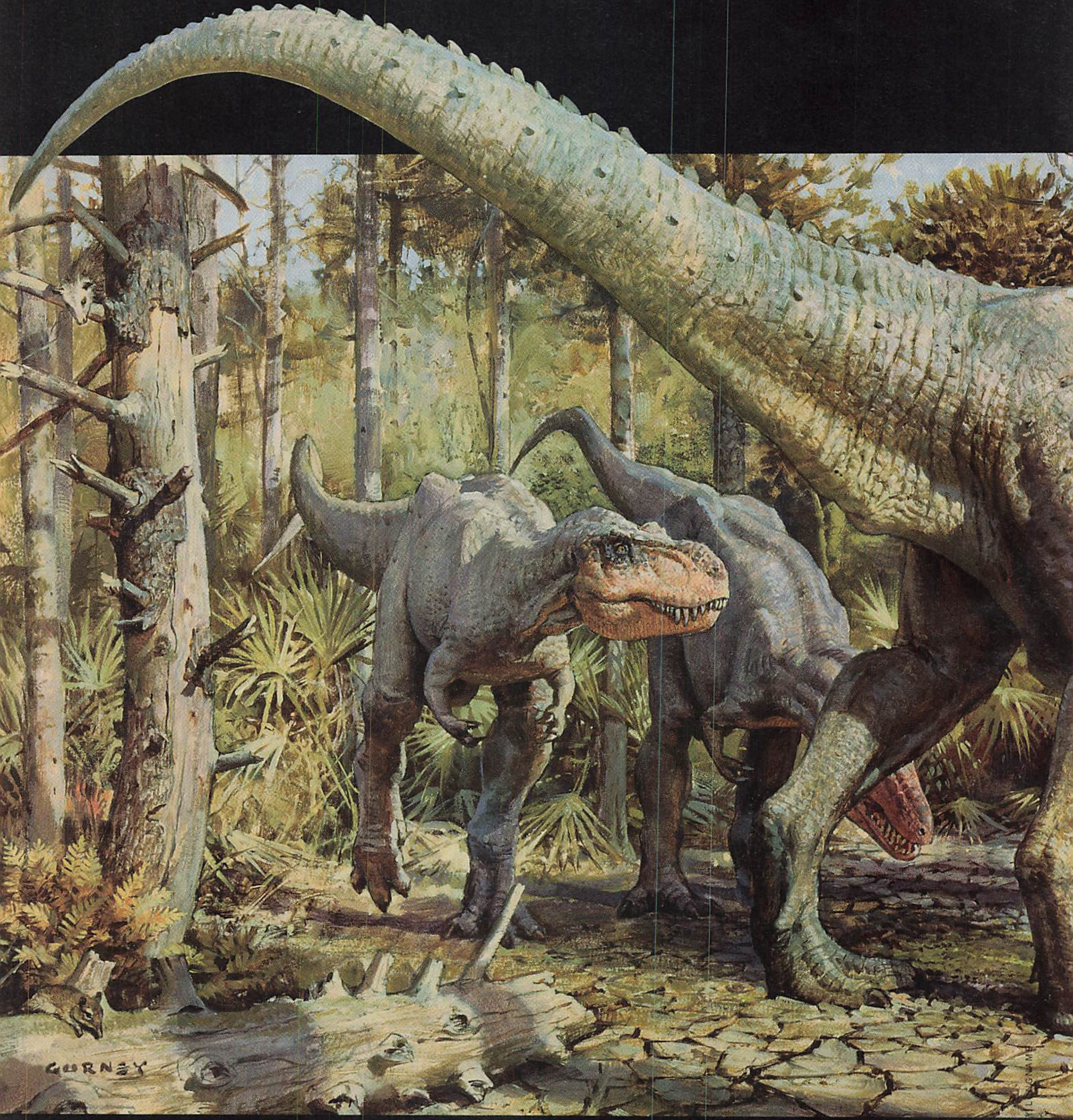
Still, one has to wonder about the amount of hoopla over dinosaurs in general and tyrannosaurs in particular. Until, of course, one goes to visit Sue. There is nothing quite like an encounter with this overpowering behemoth, which lurks in an appropriately huge hall of the main stone building of The Field Museum. Sue stands 13 feet high and is 41 feet long. Her majestic tail flails out higher than her head and longer than her body. If her flesh were still with us, she'd weigh six tons. Standing there, looking up into her eye sockets, *Homo* to dino, one has a silly but unavoidable thought: You never, ever want to meet one of these things in the woods.

And that's ultimately what being a dino fan is all about—feeling a bit frightened by animals so powerful, large, and commanding that one suspects even the mighty human brain wouldn't be much of a match. It's also why paleontologist Jack Horner's discoveries during the last three years, made while digging at the Hell Creek site in Montana, are so important. Sue is no longer the biggest *T. rex* ever found: Celeste is. Horner uncovered her last summer. In the last three summers, Horner has nearly doubled the number of *T. rex*es uncovered in all of human history. More important, he has uncovered evidence that it took a lot more than an asteroid to remove our favorite creatures from the face of the earth. Turn the page and discover more.



Right: Paleontologist Jack Horner's pick rests on the pelvis of a *Tyrannosaurus rex* dug from a site at Hell Creek Formation in Montana.

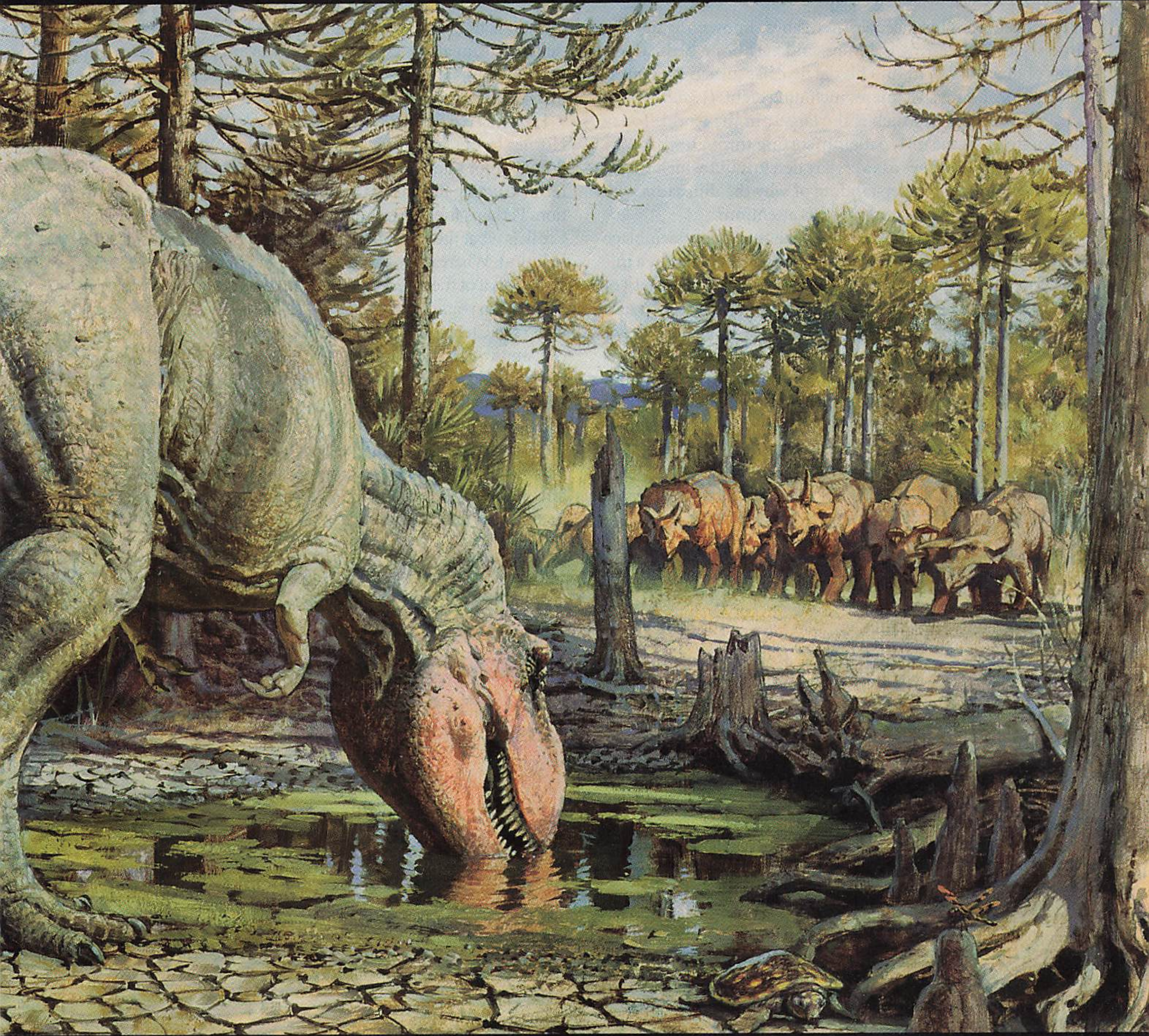
PHOTOGRAPH BY ANDREW GEIGER



Long before the asteroid impact, the diversity of plants at the Hell Creek Formation was dwindling. Conifers and ferns dominated the environment. Vegetation was patchy and thin. Dinosaurs and their prey would have had to scramble to survive. Small mammals and reptiles, however, could do better.

What Wiped Out the

Dinosaurs?



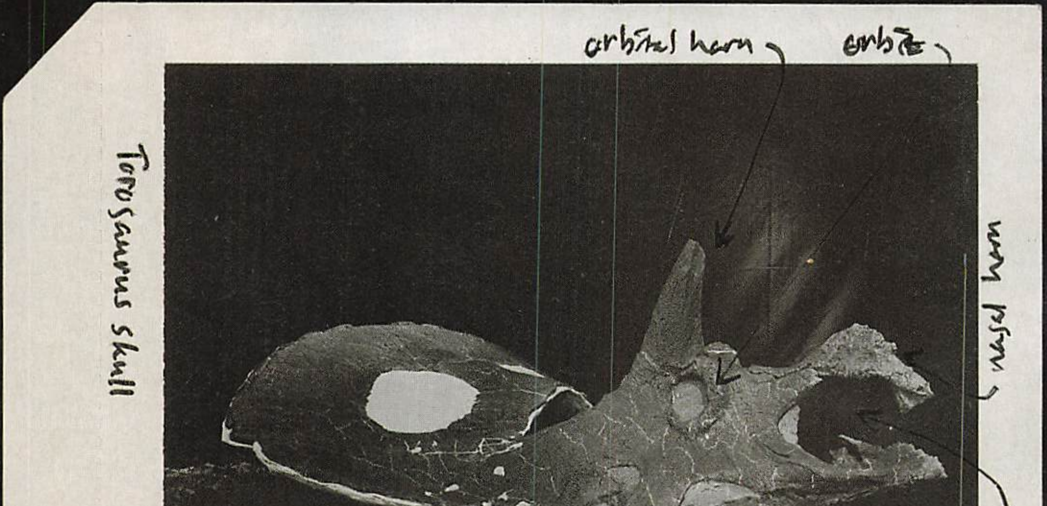
New studies suggest that dramatic climate changes were killing off behemoths even before the asteroid impact **By Edwin Dobb**

Illustration by James Gurney **Photography by Andrew Geiger**

IMAGINE THE BADLANDS OF EASTERN MONTANA, A STARK, HEAVILY ERODED LANDSCAPE OF STEEP-SIDED coulees, sandstone outcrops, and boulder-strewn washes. Vegetation is sparse, little more than sage, bunchgrass, scattered islands of scrub pine, and an occasional yucca plant. It's here, south of Fort Peck Reservoir, on a sunny spring afternoon, that you could find Jack Horner lying on his belly atop a barren hill in the Hell Creek Formation, one of the world's most famous dinosaur graveyards. The paleontologist is a big man, standing 6 feet 4 inches tall, but he might just as well be a boy again, chancing upon his first dinosaur fossil, so thoroughly absorbed is he in exploring the tiny objects only inches from his face. Horner is best known for finding large skeletons, nesting colonies, and vast bone beds where herds of dinosaurs died, and his dig here has turned up a number of outstanding specimens, including eight *Tyrannosaurus rex* skeletons, one of which is the largest in the world. Today he's sprawled in the dirt, patiently sorting through what may strike the untrained eye as everyday detritus but which might hold clues to a new understanding of why the dinosaurs perished. What exactly has captured his attention?

The technical term is *micro-site*, which means an assemblage of small fossils, some so tiny they cannot be seen without a microscope. Micro-sites often contain remains from a variety of organisms, and paleontologists use them to reconstruct a slice of everyday ancient life. At this location, for instance, Horner and two colleagues have collected lizard skull fragments; shards of turtle shell; fish teeth, scales, and vertebrae; even a handful of dinosaur toe bones. Remnants of snails, clams, frogs, crocodiles, rodent-size mammals, and other animals have been excavated in neighboring micro-sites. The fossils are found together because they were once transported by a swift-running creek or river and deposited as the flow of water slowed down or came to a standstill. What makes these miniature menageries important is that they include species that lived in or near a particular stream at the same time. "Just by picking through one of these sites," Horner explains, "we can figure out which animals occupied the same ecological space."

Exploring ecological space on an unprecedented scale has brought Horner to this remote part of the American West. He and the dozen senior scientists he has assembled for this expedition are reconstructing the ancient ecosystem of the Hell Creek Formation. Perhaps the most significant of the many interests of Hell Creek is what the formation reveals about how that world came to be lost. Whereas the age of the bottom layers is somewhat uncertain, that of the top, or most recent, layers is known precisely—64.5 million years old. That date marks the so-called K-T boundary, when the Cretaceous Period ended and the Tertiary Period began, and when the 160-million-year-long saga of the dinosaurs came to a close. In other words, the Hell Creek Formation represents the final scenes in the third act of one of evolution's most successful dramas. And the events recorded in this suite of sedimentary rock suggest that the common explanation for the extinction of the dinosaurs—a massive asteroid impact—doesn't fully account for their undoing. What's more, the Hell Creek Formation may tell us something about the fragility of life today.



Top of the Torosaur

One of the prize discoveries at Montana's Hell Creek Formation is the largest dinosaur skull ever found. The 9-foot-long skull belonged to a mature torosaur. Adults of this species probably reached at least 25 feet in length and may have weighed 4 to 5 tons. Notes on the edge of the Polaroid point out the eye (orbital horn), nasal horn, nostril, and frill, or neck shield. Although torosaurs resembled *Triceratops*, says Horner, they had holes in the frill that *Triceratops* lacked. Torosaur means "piercing reptile" in Latin.

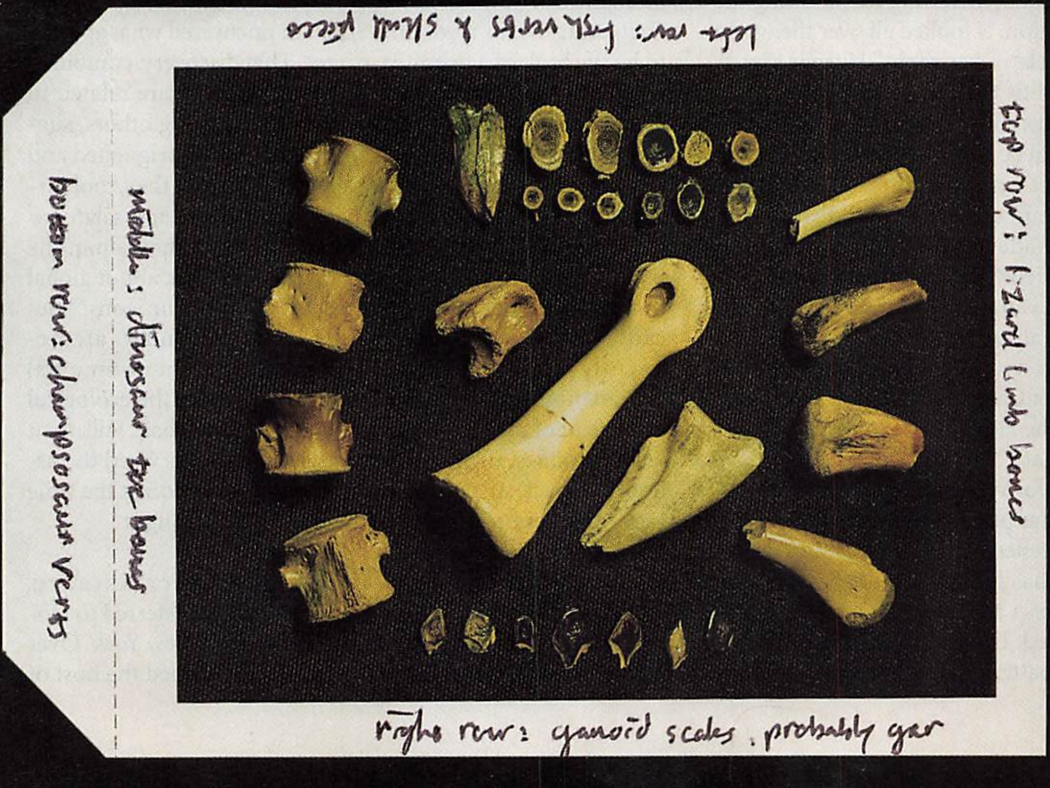
Blessed with broad expanses of fossil-bearing rock that were exposed and scoured when the last continental ice sheet retreated 18,000 years ago, eastern Montana appears early on in the development of dinosaur paleontology. In 1855 Ferdinand Vandiveer Hayden, a geologist with the United States Geological Survey, found a variety of teeth just upstream of Fort Peck Reservoir where the Missouri and Judith Rivers meet. They were later identified as belonging to dinosaurs, the first such discovery in the Western Hemisphere. Subsequent excavations in the region during the second half of the 19th century turned up nearly complete skeletons of duck-billed, horned, and armored dinosaurs. Then in 1903, while surveying the Hell Creek Formation, a collector from the American Museum of Natural History named Barnum Brown came upon the remains of an extraordinary animal no one had seen before—*Tyrannosaurus rex*. Parts of a second *T. rex* were unearthed in the same area five years later. Since then, several other skeletons have been discovered, including one in 1988 known as the Wankel *T. rex*, the first specimen to include the animal's tiny two-clawed arms.

Now three years into the five-year-long Hell Creek Project, Horner, his crews, and volunteers have picked up the pace of discovery. Their finds include the world's largest duck-billed dinosaur, the largest dinosaur skull ever excavated, and approximately 60 separate partial remains of *Triceratops*, the three-horned behemoth common to this area of North America at the time. Most impressive, however, are the tyrannosaurs. One is at least 10 percent bigger than Sue, the controversial South Dakota dinosaur that heretofore was the largest *T. rex* ever uncovered. Another, exquisitely preserved, is the oldest. Yet another is the smallest in the world, meaning it is a juvenile, which can lead to an understanding of how tyrannosaurs matured.

Fascinating as the dinosaurs may be, however, they form only one part of the comprehensive picture here. Horner and his experienced colleagues—a structural geologist; a stratigrapher; a taphonomist (one who studies what happens to animals after they die); paleontologists specializing in vertebrate, mammalian, plant, and mollusk fossils; a molecular paleontologist; and an expert on paleomagnetism—are surveying all the fauna and flora that existed during the Hell Creek period (and that survived as fossils), the ways they interacted, and how they may have evolved. In addition, they are looking for traces of rivers, lakes, and saltwater bays, which will reveal the region's climate over the course of 2 to 3 million years.

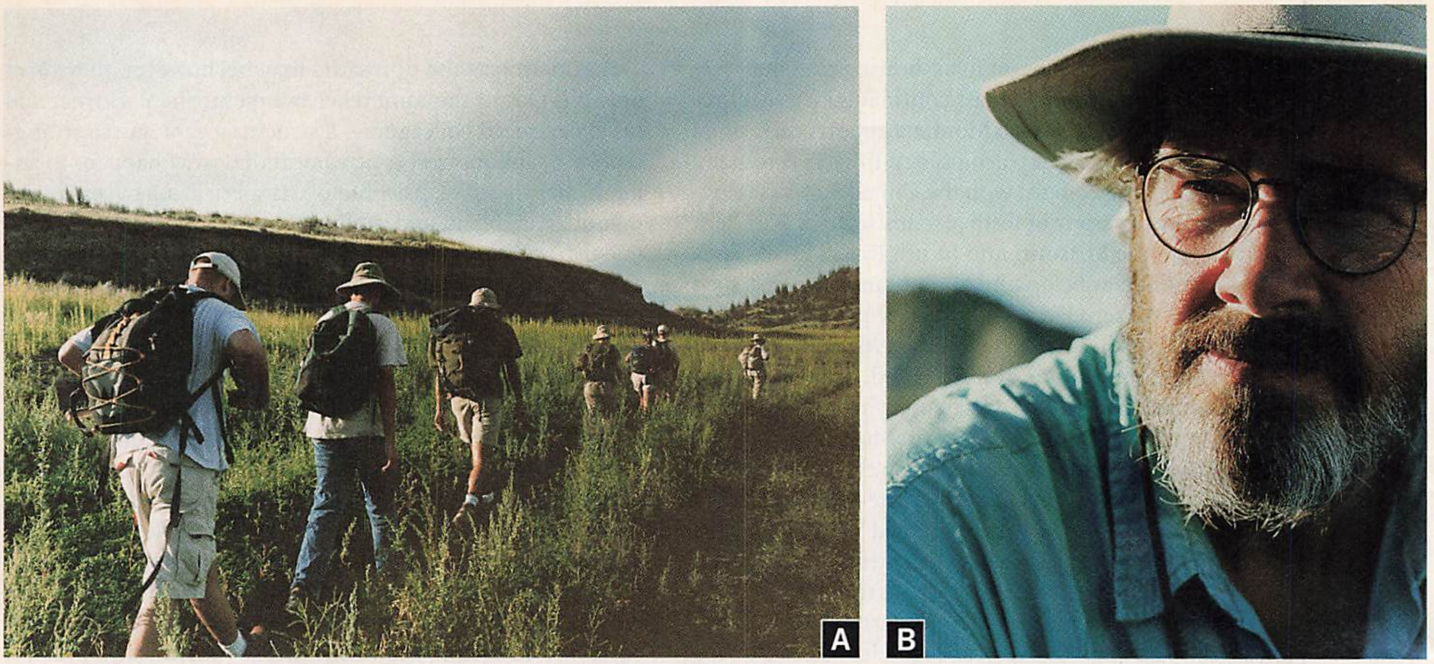
Convention has it that the Hell Creek Formation represents an uneventful period in the planet's history. During the Cretaceous Period, the oceans rose several times, flooding the continents. One part of that inundation was the Western Interior Seaway, which stretched from the Gulf of Mexico well into Canada and divided North America in two. For tens of millions of years, the seaway retreated and advanced, its western edge once advancing within 50 miles of the Rocky Mountains. Just before the Hell Creek sediments were deposited, about 68 million years ago, the seaway withdrew for good, leaving behind the configuration of continent and surrounding oceans that exists today. During the 2 to 3 million years that followed, many scientists agree, both the environment and the animal and plant populations of the region remained stable.

All that changed drastically and violently 64.5 million years ago when a giant asteroid slammed into the planet north of the Yucatán Peninsula, apparently creating a worldwide pall of dust, ash, and debris. During the next three to six months—some have postulated an aftermath that lasted up to a year—


left row: fish verts & skull pieces
top row: lizard limb bones
right row: ganoid scales. probably gar
middle: dinosaur toe bones
bottom row: champsosaur verts

Micro-site Fossils

The gigantic dinosaur skeletons found at the Hell Creek Formation tend to get all the press, but they don't tell the full story. So Horner and his team are carefully unearthing smaller fossils that re-create the environment in which the dinosaurs at Hell Creek lived. The photo at left includes (clockwise from the top) fish vertebrae and skull pieces, lizard limb bones, ganoid scales (from a garfish), and *Champsosaurus* vertebrae. In the center are dinosaur toe bones. The largest is three inches long.



(A) During the field season at Hell Creek, teams head out around 7:30 a.m., each to a different site. (B) Horner, who has been excavating dinosaurs in Montana for 30 years, supervises research for the project. The teams work independently, he says: "We don't want to influence the interpretations of the other teams."

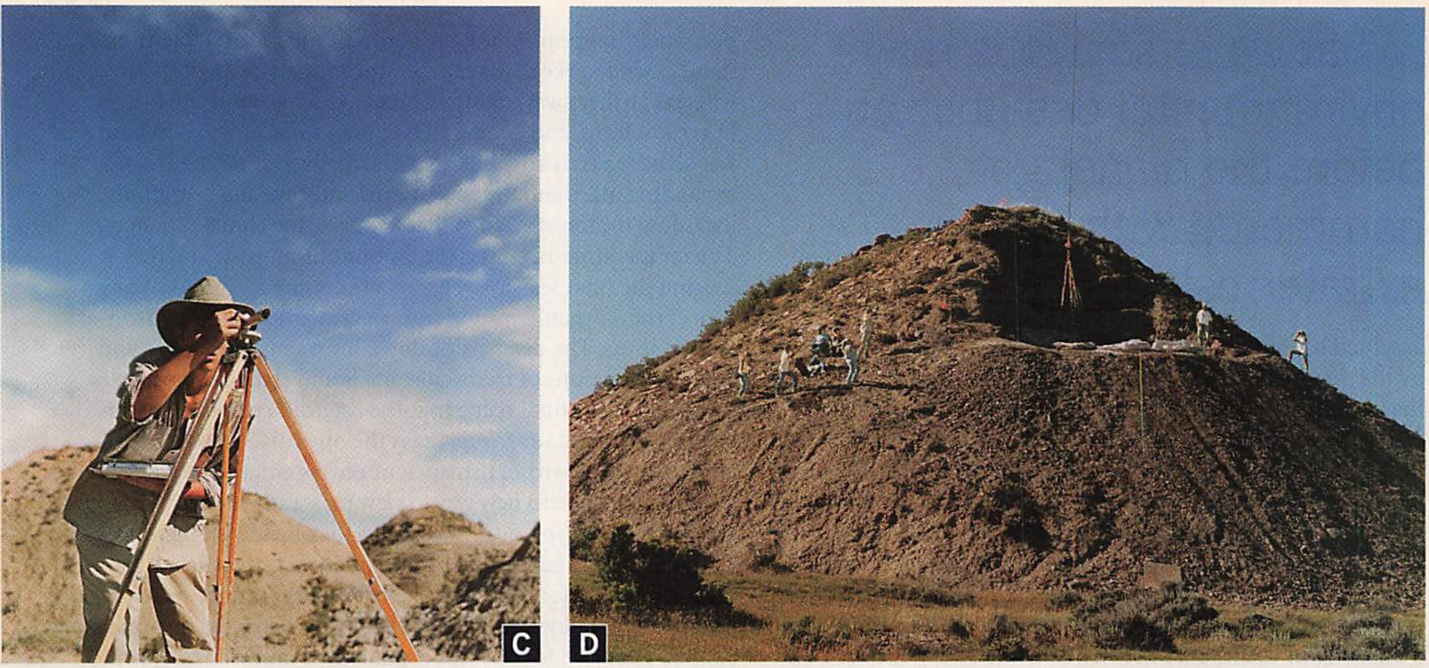
of darkness, freezing cold, and perpetual acid rain, a catastrophic die-out occurred, affecting both marine and terrestrial organisms. Among the many casualties were dinosaurs.

That has long been the accepted scenario. But no one had studied the sediment record in enough detail to determine whether the animals and plants actually endured without variation prior to the extraterrestrial impact. Everyone simply assumed it. So when Horner was casting about for a potentially fruitful location to reconstruct an ancient ecosystem, he recognized that Hell Creek offered the opportunity to pursue a number of related lines of inquiry, including reexamining the factors that led to mass extinction. "I looked all over the world for something compact and relatively simple," Horner says. A 3-million-year section would fit the bill, because it encompassed enough time for significant change, including evolution, to take place, yet would still be manageable from a research standpoint. In addition, Horner wanted sedimentary rock containing fossils of sufficient number, variety, and distribution to allow comparisons to be made between different levels—that is to say, different ages. Hell Creek had that going for it, and more. "Another reason it's so good," Horner says, "is because the Berkeley group had already collected from the top."

By "Berkeley group," Horner means William Clemens, a paleontologist at the University of California at Berkeley and one of the principal members of the Hell Creek Project. Last summer marked the 29th year that Clemens and his crews have worked in the area, searching for vertebrates, especially mammals, the group of animals that prospered most after the dinosaurs' demise. "I'm really interested in mechanisms of recovery," Clemens says. That's why he has focused on the first million years of Tertiary Period deposits above the K-T boundary as well as the part of the Hell Creek Formation that lies immediately below it. The extinction pattern that has emerged was not expected. Whereas the last of the nonavian dinosaurs certainly perished 64.5 million years ago, many other animals survived—crocodiles, for example, along with almost all the mammals, which at the time were small, some with skulls the size of a thimble. The top of the Hell Creek Formation, just before the asteroid impact, contains fossils of some 16 turtle species, representing diversity comparable to what is found in Florida today. And all but one of them, a large galapago-like tortoise, survived. "The evidence really makes you pause," Clemens says.

Clemens also points to a recent discovery made by Thomas Stidham, one of his graduate students. While working in a Late Cretaceous site in Wyoming, Stidham uncovered what appears to be the beak of a primitive parrot. That discovery, combined with other fossil finds in North America that are related to chickens, turkeys, flamingos, and loons, among others, suggests that most major groups of modern birds originated and began to diversify before the K-T boundary. Yet they, too, survived the extinction event. Finally, all the frogs and salamanders found in the Hell Creek Formation also show up in the more recent Tertiary deposits. "When you think about global disturbances today," Clemens asks, "what are our icons?" Because of their vulnerability, frogs and salamanders are frequently the first animals to succumb to environmental degradation, and thus are now looked upon as the ecological equivalent of the proverbial canary in the mine shaft. Still, they, like crocodiles, turtles, mammals, and birds, survived the asteroid impact, suggesting that the mass extinction at the time may not have been as massive as previously thought.

CLEMENS'S FINDINGS HAVE CAPTURED THE IMAGINATION OF NAN CRYSTAL Arens, a colleague at Berkeley who recently transferred to Hobart and William Smith Colleges in Geneva, New York. Over coffee one day a few years ago, Clemens described the host of



(C) Lee Hall records and maps the position of the bones of a *T. rex* skeleton. (D) This particular site, called C. Rex, contained a 45-foot-long *T. rex* skeleton—the world's largest. The site was discovered by Jack Horner's wife, Celeste, in 2000. Sites are named after the person who found them.

animals—a veritable Noah's ark—that mysteriously survived one of the most traumatic events in the planet's history. For Arens, a plant paleoecologist who believes that the fossil record should be viewed through a modern biological lens, the findings could be exploited to investigate a long-puzzling question. "Present-day alligators and crocodiles are very sensitive to cold temperatures," she says. "And acidification disrupts reproduction among frogs and salamanders." If their ancient predecessors somehow survived, but such animals as *Triceratops* and *T. rex* did not, maybe some form of environmental stress was acting disproportionately upon dinosaurs.

Recognizing an opportunity to test that hypothesis, Arens eagerly accepted Horner's invitation to participate in the effort at Hell Creek. And after five seasons of research at the site, she has come to believe that she, like Clemens, may devote the rest of her career to the dig at Hell Creek. What she and her students have already uncovered provides an intriguing clue to why the only member of the dinosaur family alive today possesses wings and feathers. First, fossil leaves and pollen excavated from the layers immediately below the K-T boundary show that the diversity of flowering plants substantially decreased in patches throughout the region *before* the extraterrestrial impact. Second, not all plants and trees were affected: Ferns, conifers, and the palmlike plants known as cycads lived to see another geological era. But the angiosperms—the flowering plants—suffered devastating losses. "Three meters [10 feet] below the asteroid event," Arens says, "we see upwards of 100 species. A meter and a half to two meters [5 to 6.5 feet] later, the number drops to 10." Among the plants and trees that exist in our contemporary landscape, angiosperms include almost everything except conifers, ferns, cycads, and ginkgoes. Think of the chain of consequences that would ensue if 90 percent of all plant species disappeared.

Now imagine this occurring 65 million or so years ago. According to Arens, one of the many insights that conservation biologists have gleaned from their study of living ecosystems is that different organisms respond differently to environmental stress. It is also known that dinosaurs experienced a great deal of turnover on the species level. The best explanation for this turnover is that whenever environmental pressure increased dramatically, certain fauna went extinct while others evolved into new forms. Consequently, general lineages remained intact, but the animals that survived differed from their ancestors. If, as Arens's research suggests, vegetation suddenly became patchier, herbivores like *Triceratops* and *Edmontosaurus*, as well as the carnivores that ate them, like *T. rex*, would have found day-to-day survival much more difficult. "They would've been set up for extinction," she concludes.

At the very least, the research supports a picture of Hell Creek more eventful than the conventional perspective. The climate almost certainly changed. Near the top of the section, Arens has found leaves with toothed edges, which in contemporary plants is associated with cooler temperatures. And if two petrified tree-trunk segments recently unearthed from the lower, earlier part of the formation are shown to possess rings, then seasonality will also have been established. That would probably mean they experienced a wet-dry cycle, because it is extremely unlikely that the temperature fell below freezing.

None of this evidence of environmental variation surprises Joseph Hartman, another key member of the project. Hartman, a paleontologist at the University of North Dakota in Grand Forks, specializes in fossil mollusks—clams and snails. He tracks them "as proxies for changes to the climate and landscape." And what the humble mollusks have revealed is that Hell Creek was very dynamic indeed.

Hartman bases his interpretation on the location and movement of water, both freshwater and salt water. Recall the widely

> 'What we're seeing is major environmental destabilization before the planet got hammered with a large extraterrestrial object'

accepted belief that the Western Interior Seaway had receded by the time the Hell Creek Formation took shape. Recall, too, that sediment deposits in the region clearly indicate that freshwater rivers, originating in the mountains to the west, were present throughout the period of Hell Creek deposition. And wherever streams run for a sufficiently long time, freshwater clams and snails colonize in abundance. Yet at the bottom of Hell Creek, very few such fossils are found. Moving up, or forward in time, however, the mollusks rapidly diversify. Then the trend reverses direction again, with the number of species dwindling in the layers of rock below the K-T boundary. As was the case with flowering plants, a staggering 90 percent of all freshwater mollusks apparently went extinct before the impact event. Moreover, the fossils that do appear at the end of the Late Cretaceous represent a distinctive fauna not found in the Tertiary rock above the K-T boundary.

What does Hartman make of this record? In the past, he notes, the number and diversity of mollusks diminished whenever the seaway rose and extended its reach into the west. The pattern of mollusk loss—species disappearing, then diversifying, followed again by decline—tells him that the sea continued to transgress periodically during the Hell Creek time, altering drainages and other aspects of the landscape and making it impossible for freshwater clams and snails to thrive. How exactly all the project findings—the decline of angiosperms, mollusks, and dinosaurs; the rising and falling sea; the cooling climate—fit together isn't clear yet. But they nonetheless indicate that the Hell Creek Formation represents a time of widespread ecological disturbance. "What we're seeing," Hartman says, "is major environmental destabilization before the planet got hammered with an extraterrestrial object."

ONCE AGAIN, IMAGINE THE BADLANDS OF EASTERN MONTANA. But in this picture no paleontologist appears. An extremely distant cousin, the largest mammal in existence at the time, is about the size of a field mouse, and it isn't likely to be observed because it comes out of hiding only at night. You are gazing north, and before you lies a broad, flat coastal plain. To the east is the shallow, winding shoreline of a continental sea, to the west a mammoth river system that in breadth and complexity and intensity rivals the network of tributaries in the Amazon basin today, all of which drains eastward, into the sea. Some of the larger streams follow roughly the same course for long periods. But other channels, and there are hundreds of them, often change direction, intersecting, interrupting, continually reshaping the landscape and depositing huge volumes of sediment. All manner of ephemeral features—oxbow lakes, ponds, dams, swamps—appear and disappear. Along the banks of the more stable rivers stand dawn redwood, water pine, and a variety of angiosperms, whereas farther away, claiming higher, drier ground, are forests of cycads, ferns, and conifers. Over the course of 2 to 3 million years, the sea rises and falls. It occasionally inundates the land, expanding miles and miles westward and covering everything, including the forests. When that happens, the climate changes. The temperature rises and the amount of moisture increases. During the final seaway transgression, some 65 million years ago, certain organisms undergo a great amount of environmental stress. The diversity of flowering plants plummets, and entire populations of freshwater snails and clams vanish.

It's upon this final scene that the asteroid collision was superimposed, and *superimposed* is the operative word. In their attempt to reconstruct this ancient ecosystem, the Hell Creek team has developed a new way to view mass extinction. "Maybe," Arens explains, "you need two things to coincide geologically." The first is changes to the environment that significantly alter habitat, in effect "altering the rules of the game," as Arens puts it, so that physical characteristics and behavior that once proved adaptive for certain organisms—dinosaurs, for instance, that relied on flowering plants for food—no longer work as well. If on top of that pressure, a large, instantaneous ecological disturbance is added, the flora and fauna already struggling to survive are likely to die. That in fact is what Horner hypothesizes happened to *Triceratops, Edmontosaurus, T. rex,* and the rest of their diminishing kin at the end of the Hell Creek period. The asteroid may well have been the knockout blow in a fight the dinosaurs had already lost.

Two years of prospecting remain in the Hell Creek Project, followed by an unknown amount of time for specimen preparation. Horner is already planning a sweeping new exhibit at the Museum of the Rockies, in Bozeman, Montana, where he is curator of paleontology. Called *Dinosaurs Under the Big Sky,* it will recount through fossil displays the whole history of dinosaurs in Montana, the final chapter of which brings to life the plants and animals of the Hell Creek Formation. The initial draw, of course, will be the dinosaurs whose names cannot be pronounced without a superlative attached—the biggest, youngest, and oldest tyrannosaurs; the horned dinosaur skull that dwarfs all others; and the edmontosaur, which at about 48 feet long is the largest duck-billed dinosaur in existence. But whether re-creating the miniature world of a micro-site or the complex features of an entire region, the aim of the exhibit will be to further acquaint the public with the principles of evolution and ecology. And it will be much more than a history lesson. For if the Hell Creek team's two-punch theory of mass extinction is correct, we may be on the brink of our own boundary event.

"We could very well be in an interglacial period that's part of a larger pattern of climate fluctuation," Arens warns—a time of severe environmental stress. Superimpose upon that the worldwide disturbances that human beings are causing, and another sudden, catastrophic die-out could be in the offing. Were that the case, we would be the contemporary equivalent of the asteroid that collided with Earth all those millions of years ago. ☒

Opposite: Excavations at Hell Creek have turned up *T. rex* skeletons at eight different sites. This specimen turned out to be a duck-billed dinosaur.

T-REX

Does the Universe Exist if We're Not Looking?

Eminent physicist John Wheeler says he has only enough time left to work on one idea: that human consciousness shapes not only the present but the past as well

BY TIM FOLGER ~ PHOTOGRAPHY BY DAN WINTERS

THE WORLD SEEMS TO BE PUTTING ITSELF TOGETHER PIECE BY piece on this damp gray morning along the coast of Maine. First the spruce and white pine trees that cover High Island materialize from the fog, then the rocky headland, and finally the sea, as if the mere act of watching has drawn them all into existence. And that may indeed be the case. While this misty genesis unfolds, the island's most eminent resident discusses notions that still perplex him after seven decades in physics, including his gut feeling that the very universe may be constantly emerging from a haze of possibility, that we inhabit a cosmos made real in part by our own observations.

* * *

JOHN WHEELER, SCIENTIST AND DREAMER, COLLEAGUE OF ALBERT EINSTEIN and Niels Bohr, mentor to many of today's leading physicists, and the man who chose the name "black hole" to describe the unimaginably dense, light-trapping objects now thought to be common throughout the universe, turned 90 last July. He is one of the last of the towering figures of 20th-century physics, a member of the generation that plumbed the mysteries of quantum mechanics and limned the utmost reaches of space and time. After a lifetime of fundamental contributions in fields ranging from atomic physics to cosmology, Wheeler has concerned himself in his later years with what he calls "ideas for ideas."

"I had a heart attack on January 9, 2001," he says, "I said, 'That's a signal. I only have a limited amount of time left, so I'll concentrate on one question: How come existence?'"

Why does the universe exist? Wheeler believes the quest for an answer to that question inevitably entails wrestling with the implications of one of the strangest aspects of modern physics: According to the rules of quantum mechanics, our observations influence the universe at the most fundamental levels. The boundary between an objective "world out there" and our own subjective consciousness that seemed so clearly defined in physics before the eerie discoveries of the 20th century blurs in quantum mechanics. When physicists look at the basic constituents of reality—atoms and their innards, or the particles of light called photons—what they see depends on how they have set up their experiment. A physicist's observations determine whether an atom, say, behaves like a fluid wave or a hard particle, or which path it follows in traveling from one point to another. From the quantum perspective the universe is an extremely interactive place. Wheeler takes the quantum view and runs with it.

As Wheeler voices his thoughts, he laces his fingers behind his large head, leans back onto a sofa, and gazes at the ceiling or perhaps far beyond it. He sits with his back to a wide window. Outside, the fog is beginning to lift on what promises to be a hot summer day. On an end table near the sofa rests a large oval rock, with one half polished black so that its surface resembles the Chinese yin-yang symbol. "That rock is about 200 million years old," says Wheeler. "One revolution of our galaxy."

Although Wheeler's face looks careworn and sober, it becomes almost boyish when he smiles, as he does when I extend a hand to help him from the couch and he says, "Ah, antigravity." Wheeler is short and sturdily built, with sparse white hair. He retains an impish fascination with fireworks—an enthusiasm

Opposite: John Archibald Wheeler, high priest of quantum mysteries, suspects that reality exists not because of physical particles but rather because of the act of observing the universe. "Information may not be just what we *learn* about the world," he says. "It may be what *makes* the world."

that cost him part of a finger when he was young—and has on occasion lit Roman candles in the corridors of Princeton, where he became a faculty member in 1938 and where he still keeps an office. At one point a loud bang interrupts our interview. Wheeler's son, who lives on a cliff a few hundred yards away, has fired a small cannon, a gift from Wheeler.

Wheeler is gracious to a fault; one colleague describes him as "a gentleman hidden inside a gentleman." But that courtly demeanor also hides something else: one of the most adventurous minds in physics. Instead of shying away from questions about the meaning of it all, Wheeler relishes the profound and the paradoxical. He was an early advocate of the anthropic principle, the idea that the universe and the laws of physics are fine-tuned to permit the existence of life. For the past two decades, though, he has pursued a far more provocative idea for an idea, something he calls genesis by observership. Our observations, he suggests, might actually contribute to the creation of physical reality. To Wheeler we are not simply bystanders on a cosmic stage; we are shapers and creators living in a participatory universe.

Wheeler's hunch is that the universe is built like an enormous feedback loop, a loop in which we contribute to the ongoing creation of not just the present and the future but the past as well. To illustrate his idea, he devised what he calls his "delayed-choice experiment," which adds a startling, cosmic variation to a cornerstone of quantum physics: the classic two-slit experiment.

That experiment is exceedingly strange in its own right, even without Wheeler's extra kink thrown in. It illustrates a key principle of quantum mechanics: Light has a dual nature. Sometimes light behaves like a compact particle, a photon; sometimes it seems to behave like a wave spread out in space, just like the ripples in a pond. In the experiment, light—a stream of photons—shines through two parallel slits and hits a strip of photographic film behind the slits. The experiment can be run two ways: with photon detectors right beside each slit that allow physicists to observe the photons as they pass, or with detectors removed, which allows the photons to travel unobserved. When physicists use the photon detectors, the result is unsurprising: Every photon is observed to pass through one slit or the other. The photons, in other words, act like particles.

But when the photon detectors are removed, something weird occurs. One would expect to see two distinct clusters of dots on the film, corresponding to where individual photons hit after randomly passing through one slit or the other. Instead, a pattern of alternating light and dark stripes appears. Such a pattern could be produced only if the photons are behaving like waves, with each individual photon spreading out and surging against both slits at once, like a breaker hitting a jetty. Alternating bright stripes in the pattern on the film show where crests from those waves overlap; dark stripes indicate that a crest and a trough have canceled each other.

The outcome of the experiment depends on what the physicists try to measure: If they set up detectors beside the slits, the photons act like ordinary particles, always traversing one route or the other, not both at the same time. In that case the striped pattern doesn't appear on the film. But if the physicists remove the detectors, each photon seems to travel both routes simultaneously like a tiny wave, producing the striped pattern.

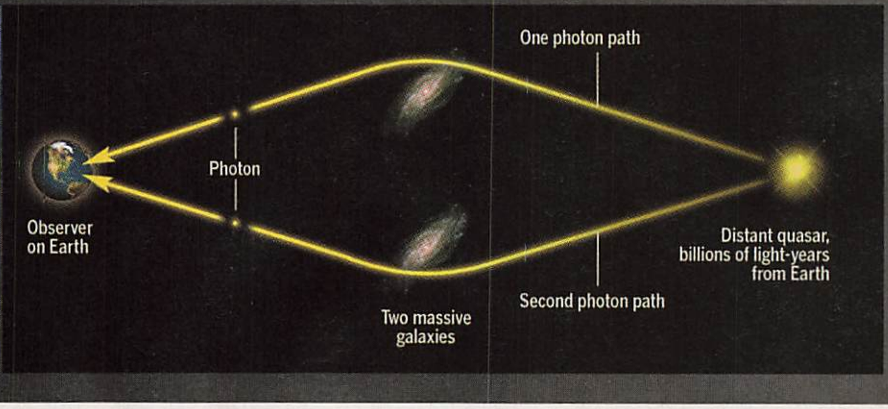
Wheeler has come up with a cosmic-scale version of this experiment that has even weirder implications. Where the classic experiment demonstrates that physicists' observations determine the behavior of a photon in the present, Wheeler's version shows that our observations in the present can affect how a photon behaved in the past.

To demonstrate, he sketches a diagram on a scrap of paper. Imagine, he says, a quasar—a very luminous and very remote young galaxy. Now imagine that there are two other large galaxies between Earth and the quasar. The gravity from massive objects like galaxies can bend light, just as conventional glass lenses do. In Wheeler's experiment the two huge galaxies substitute for the pair of slits; the quasar is the light source. Just as in the two-slit experiment, light—photons—from the quasar can follow two different paths, past one galaxy or the other.

Suppose that on Earth, some astronomers decide to observe the quasars. In this case a telescope plays the role of the photon detector in the two-slit experiment. If the astronomers point a telescope in the direction of one of the two intervening galaxies, they will see photons from the quasar that were deflected by that galaxy; they would get the same result by looking at the other galaxy. But the astronomers could also mimic the second part of the two-slit experiment. By carefully arranging mir-

Seeing Double

In his delayed-choice thought experiment, Wheeler suggests that a single photon emitted from a distant quasar (far right) can simultaneously follow two paths to Earth, even if those paths are separated by many light-years. Here one photon travels past two different galaxies, with both routes deflected by the gravitational pull of the galaxies. Stranger still, Wheeler theorizes, the observations astronomers make on Earth today decide the path the photon took billions of years ago.



GRAPHIC BY MATT ZANG

rors, they could make photons arriving from the routes around both galaxies strike a piece of photographic film simultaneously. Alternating light and dark bands would appear on the film, identical to the pattern found when photons passed through the two slits.

Here's the odd part. The quasar could be very distant from Earth, with light so faint that its photons hit the piece of film only one at a time. But the results of the experiment wouldn't change. The striped pattern would still show up, meaning that a lone photon not observed by the telescope traveled both paths toward Earth, even if those paths were separated by many light-years. And that's not all.

By the time the astronomers decide which measurement to make—whether to pin down the photon to one definite route or to have it follow both paths simultaneously—the photon could have already journeyed for billions of years, long before life appeared on Earth. The measurements made *now,* says Wheeler, determine the photon's past. In one case the astronomers create a past in which a photon took both possible routes from the quasar to Earth. Alternatively, they retroactively force the photon onto one straight trail toward their detector, even though the photon began its jaunt long before any detectors existed.

It would be tempting to dismiss Wheeler's thought experiment as a curious idea, except for one thing: It has been demonstrated in a laboratory. In 1984 physicists at the University of Maryland set up a tabletop version of the delayed-choice scenario. Using a light source and an arrangement of mirrors to provide a number of possible photon routes, the physicists were able to show that the paths the photons took were not fixed until the physicists made their measurements, even though those measurements were made after the photons had already left the light source and begun their circuit through the course of mirrors.

Wheeler conjectures we are part of a universe that is a work in progress; we are tiny patches of the universe looking at itself—and building itself. It's not only the future that is still undetermined but the past as well. And by peering back into time, even all the way back to the Big Bang, our present observations select one out of many possible quantum histories for the universe.

Does this mean humans are necessary to the existence of the universe? While conscious observers certainly partake in the creation of the participatory universe envisioned by Wheeler, they are not the only, or even primary, way by which quantum potentials become real. Ordinary matter and radiation play the dominant roles. Wheeler likes to use the example of a high-energy particle released by a radioactive element like radium in Earth's crust. The particle, as with the photons in the two-slit experiment, exists in many possible states at once, traveling in every possible direction, not quite real and solid until it interacts with something, say a piece of mica in Earth's crust. When that happens, one of those many different probable outcomes becomes real. In this case the mica, not a conscious being, is the object that transforms what might happen into what does happen. The trail of disrupted atoms left in the mica by the high-energy particle becomes part of the real world.

At every moment, in Wheeler's view, the entire universe is filled with such events, where the possible outcomes of countless interactions become real, where the infinite variety inherent in quantum mechanics manifests as a physical cosmos. And we see only a tiny portion of that cosmos. Wheeler suspects that most of the universe consists of huge clouds of uncertainty that have not yet interacted either with a conscious observer or even with some lump of inanimate matter. He sees the universe as a vast arena containing realms where the past is not yet fixed.

Wheeler is the first to admit that this is a mind-stretching idea. It's not even really a theory but more of an intuition about what a final theory of everything might be like. It's a tenuous lead, a clue that the mystery of creation may lie not in the distant past but in the living present. "This point of view is what gives me hope that the question—How come existence?—can be answered," he says.

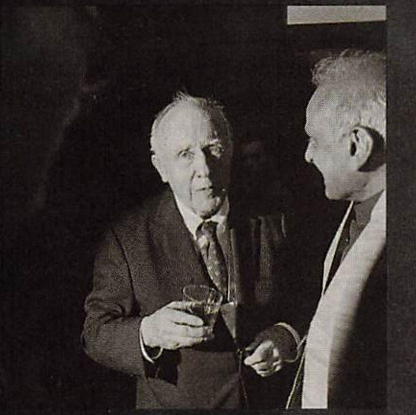
~

WILLIAM WOOTTERS, ONE OF WHEELER'S many students and now a professor of physics at Williams College in Williamstown, Massachusetts, sees Wheeler as an almost oracular figure. "I think asking this question—How come existence?—is a good thing," Wootters says. "Why not see how far you can stretch? See where that takes you. It's got to generate at least some good ideas, even if the question doesn't get answered. John is interested in the significance of quantum measurement, how it creates an actuality of what was a mere potentiality. He has come to think of that as the essential building block of reality."

In his concern for the nature of quantum measurements, Wheeler is addressing one of the most confounding aspects of modern physics: the relationship between the observations and the outcomes of experiments on quantum systems. The

Birthday Bash

Andrei Linde, top, one of the principal architects of inflationary theory, helps celebrate John Wheeler's pre-91st birthday at a gathering at Princeton University. Linde is using his hands to illustrate that our universe may have been paired with another when it was born. Wheeler, with glass in hand (bottom), chats with Ravi Ravindra, a professor emeritus of comparative religion at Dalhousie University in Nova Scotia.



PHOTOGRAPHS BY BRIAN FINKE

> 'I can't imagine a theory of everything that ignores consciousness,' Andrei Linde says. 'In the absence of observers, our universe is dead'

problem goes back to the earliest days of quantum mechanics and was formulated most famously by the Austrian physicist Erwin Schrödinger, who imagined a Rube Goldberg–type of quantum experiment with a cat.

Put a cat in a closed box, along with a vial of poison gas, a piece of uranium, and a Geiger counter hooked up to a hammer suspended above the gas vial. During the course of the experiment, the radioactive uranium may or may not emit a particle. If the particle is released, the Geiger counter will detect it and send a signal to a mechanism controlling the hammer, which will strike the vial and release the gas, killing the cat. If the particle is not released, the cat will live. Schrödinger asked, What could be known about the cat before opening the box?

If there were no such thing as quantum mechanics, the answer would be simple: The cat is either alive or dead, depending on whether a particle hit the Geiger counter. But in the quantum world, things are not so straightforward. The particle and the cat now form a quantum system consisting of all possible outcomes of the experiment. One outcome includes a dead cat; another, a live one. Neither becomes real until someone opens the box and looks inside. With that observation, an entire consistent sequence of events—the particle jettisoned from the uranium, the release of the poison gas, the cat's death—at once becomes real, giving the appearance of something that has taken weeks to transpire. Stanford University physicist Andrei Linde believes this quantum paradox gets to the heart of Wheeler's idea about the nature of the universe: The principles of quantum mechanics dictate severe limits on the certainty of our knowledge.

"You may ask whether the universe really existed before you start looking at it," he says. "That's the same Schrödinger cat question. And my answer would be that the universe *looks* as if it existed before I started looking at it. When you open the cat's box after a week, you're going to find either a live cat or a smelly piece of meat. You can say that the cat looks as if it were dead or as if it were alive during the whole week. Likewise, when we look at the universe, the best we can say is that it looks as if it were there 10 billion years ago."

Linde believes that Wheeler's intuition of the participatory nature of reality is probably right. But he differs with Wheeler on one crucial point. Linde believes that conscious observers are an essential component of the universe and cannot be replaced by inanimate objects.

"The universe and the observer exist as a pair," Linde says. "You can say that the universe is there only when there is an observer who can say, Yes, I see the universe there. These small words—*it looks like it was here*—for practical purposes it may not matter much, but for me as a human being, I do not know any sense in which I could claim that the universe is here in the absence of observers. We are together, the universe and us. The moment you say that the universe exists without any observers, I cannot make any sense out of that. I cannot imagine a consistent theory of everything that ignores consciousness. A recording device cannot play the role of an observer, because who will read what is written on this recording device? In order for us to see that something happens, and say to one another that something happens, you need to have a universe, you need to have a recording device, and you need to have us. It's not enough for the information to be stored somewhere, completely inaccessible to anybody. It's necessary for somebody to look at it. You need an observer who looks at the universe. In the absence of observers, our universe is dead."

* * *

WILL WHEELER'S QUESTION—HOW COME existence?—ever be answered? Wootters is skeptical. "I don't know if human intelligence is capable of answering that question," he says. "We don't expect dogs or ants to be able to figure out everything about the universe. And in the sweep of evolution, I doubt that we're the last word in intelligence. There might be higher levels later. So why should we think we're at the point where we can understand everything? At the same time I think it's great to ask the question and see how far you can go before you bump into a wall."

Linde is more optimistic.

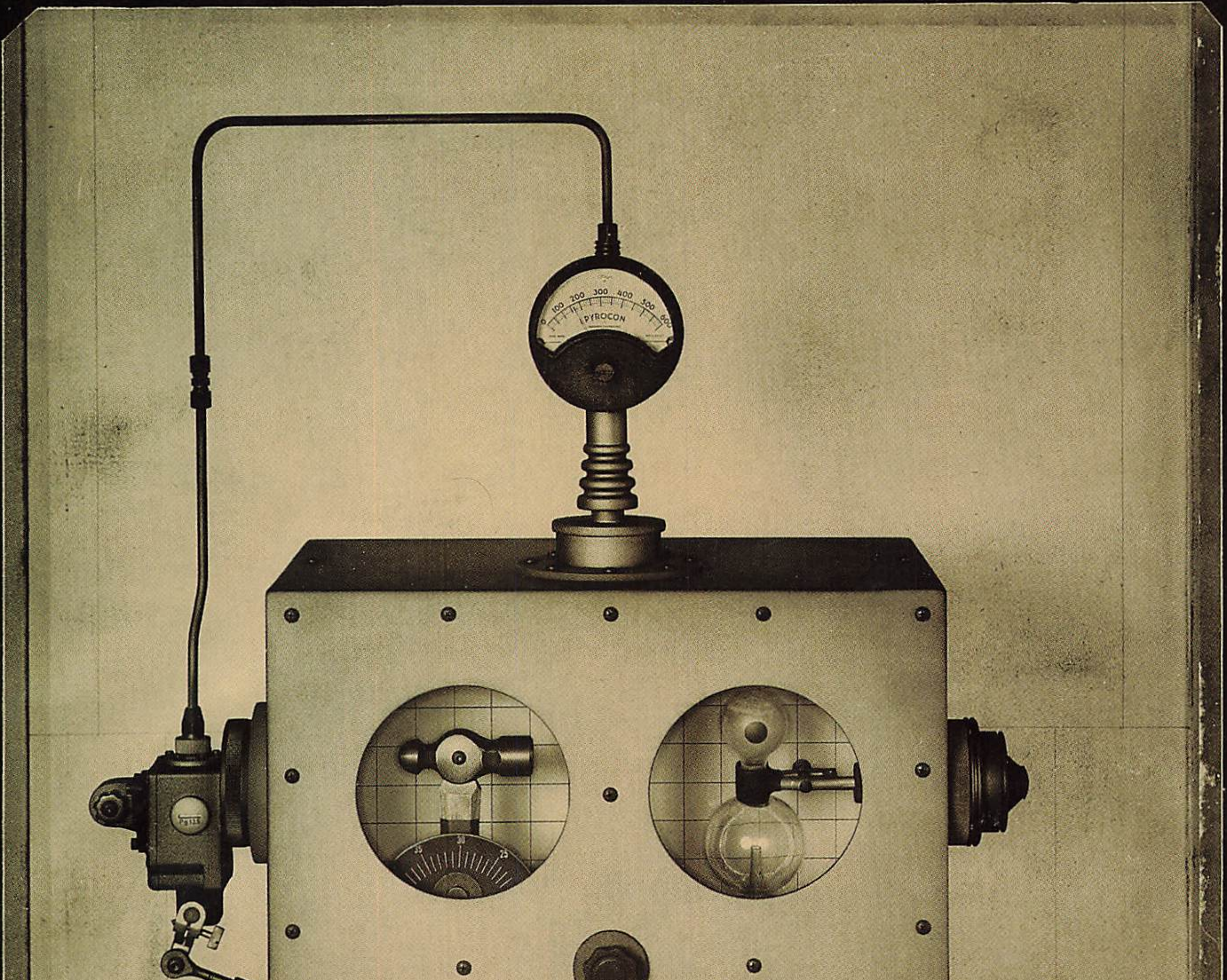
"You know, if you say that we're smart enough to figure everything out, that is a very arrogant thought. If you say that we're not smart enough, that is a very humiliating thought. I come from Russia, where there is a fairy tale about two frogs in a can of sour cream. The frogs were drowning in the cream. There was nothing solid there; they could not jump from the can. One of the frogs understood there was no hope, and he stopped beating the sour cream with his legs. He just died. He drowned in sour cream. The other one did not want to give up. There was absolutely no way it could change anything, but it just kept kicking and kicking and kicking. And then all of a sudden, the sour cream was churned into butter. Then the frog stood on the butter and jumped out of the can. So you look at the sour cream and you think, 'There is no way I can do anything with that.' But sometimes, unexpected things happen.

"I'm happy that some people who previously thought this question—How come existence?—was meaningless did not stop us from asking it. We all learned from people like John Wheeler, who asks strange questions and gives strange answers. You may agree or disagree with his answers. But the very fact that he asks these questions, and suggests some plausible—and implausible—answers, it has shaken these boundaries of what is possible and what is impossible to ask."

And what does the oracle of High Island himself think? Will we ever understand why the universe came into being?

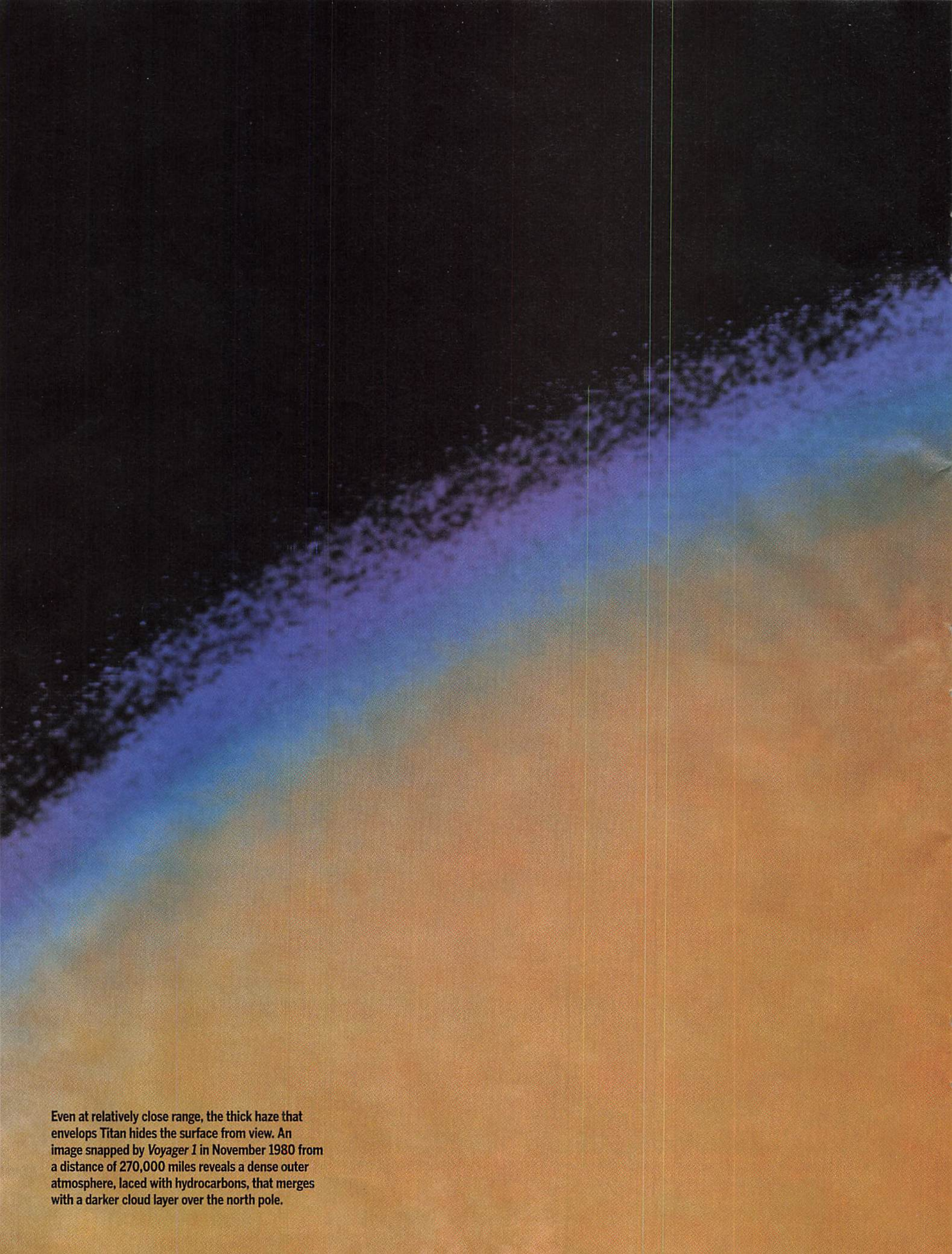
"Or at least how," he says. "Why is a trickier thing." Wheeler points to the example of Charles Darwin in the 19th century and how he provided a simple explanation—evolution through natural selection—for what seemed an utterly intractable problem: how to explain the origin and diversity of life on Earth. Does Wheeler think that physicists might one day have a similarly clear understanding of the origin of the universe?

"Absolutely," he says. "Absolutely." ☒

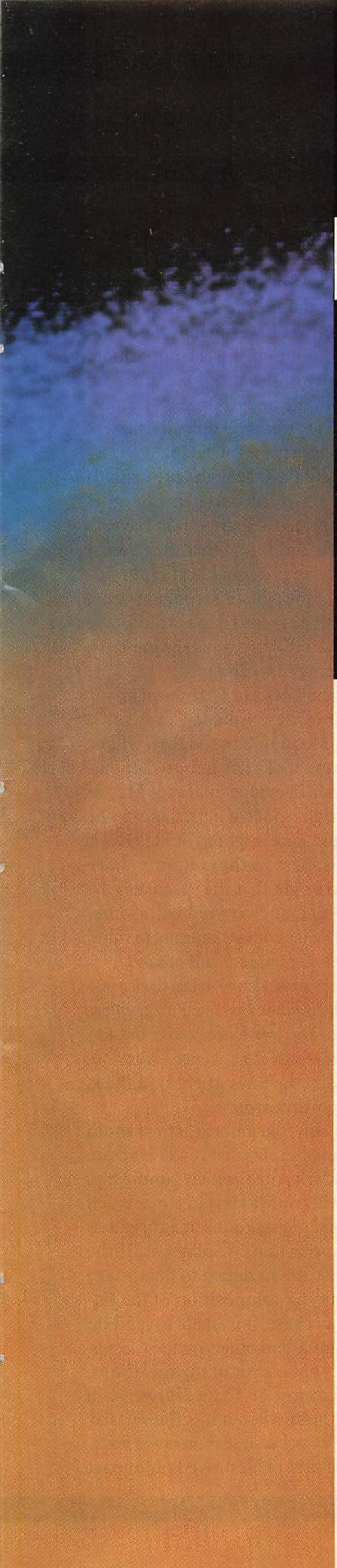


Schrödinger's Cat

Erwin Schrödinger, a founding father of quantum mechanics, asked what would happen to a cat locked in a box with a radioactive element that may or may not trigger the release of poison gas during the experiment. The short answer: The cat's fate is undecided until the moment someone observes the experiment.

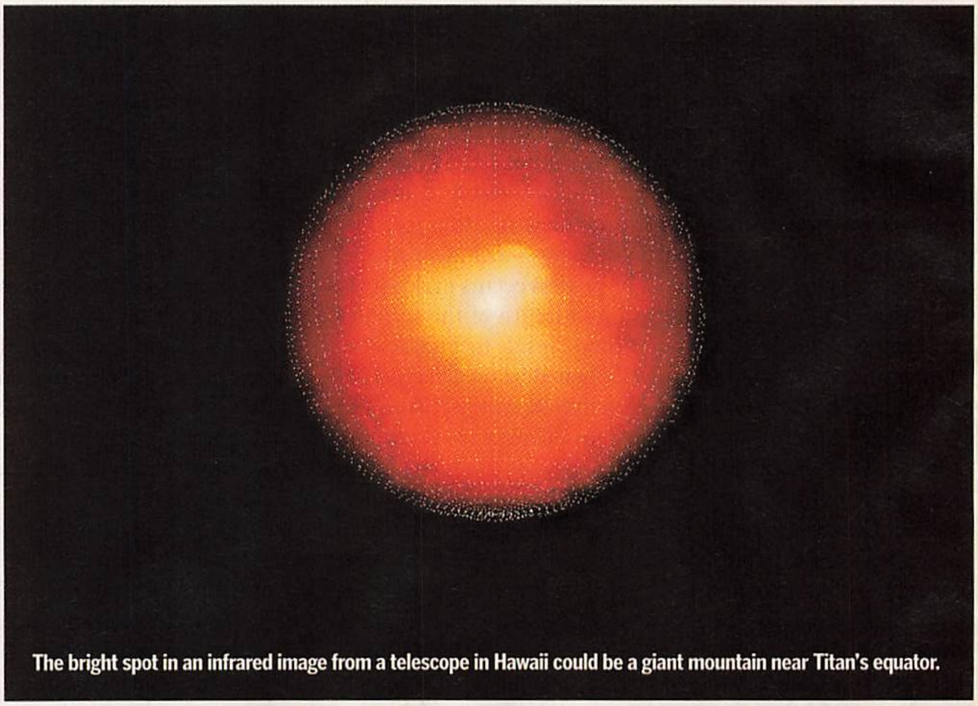


Even at relatively close range, the thick haze that envelops Titan hides the surface from view. An image snapped by *Voyager 1* in November 1980 from a distance of 270,000 miles reveals a dense outer atmosphere, laced with hydrocarbons, that merges with a darker cloud layer over the north pole.



Titan's time warp

IS SATURN'S HUGE MOON JUST LIKE EARTH 4 BILLION YEARS AGO? SCIENTISTS NAVIGATING THE *CASSINI* SPACECRAFT FOR A RENDEZVOUS WITH SMOGGY TITAN ARE BETTING ON IT



The bright spot in an infrared image from a telescope in Hawaii could be a giant mountain near Titan's equator.

BY KATHY A. SVITIL

ONE NIGHT IN 1655, DUTCH OPTICIAN CHRISTIAAN HUYGENS turned his handmade telescope toward Saturn, discovered its planet-size moon Titan, and glimpsed a world of mysteries that has perplexed astronomers for more than 300 years. Titan is enveloped in a mud-orange cocoon of nitrogen and methane that is seven times denser than Earth's atmosphere and blocks any view of its surface. A flyby *Voyager 1* made in 1980 offered little more than a closer view of the same smoggy atmosphere. Recent infrared images have shown more tantalizing hints of a bizarre environment, where chilly oceans of ethane lap up against cliffs of eroded ice, and clouds burst open with showers of liquid hydrocarbons. "On Titan," the late Carl Sagan once mused, "organic matter is falling from the skies like manna from heaven."

Not that this lonely outpost more than 800 million miles from Earth should be mistaken for any kind of paradise. The human ear would be in pain on Titan, which is under about 1½ times the atmospheric pressure on Earth, a lot like being at the bottom of a swimming pool. A day on Titan is long—about 16 Earth days—and extremely frigid. Even at high noon the distant sun casts only a faint glow, and temperatures hover around –292 degrees Fahrenheit. But what intrigues planetary scientists the most about Titan is that recent evidence suggests the bizarre chemical processes taking place there are a lot like those that occurred on Earth some 4 billion years ago, when early forms of life began to appear.

"Titan may be the closest replica we have of the early Earth," says Jonathan Lunine of the University of Arizona's Lunar and Planetary Laboratory. "On Earth the entire record of that period has been destroyed. But on Titan it's happening now. We can see some of the chemical steps that led toward life."

Like Earth, Titan has a nitrogen-rich atmosphere, and it's the only other body in our solar system thought to have global weather cycles. "You have liquid on the surface, liquid in the atmosphere, and rain from the atmosphere to the surface," says Caitlin Griffith, another researcher at the Lunar and Planetary Lab. "That cycle of liquid is very important to how Earth's biosphere works." Titan's atmosphere also has heady doses of methane, nature's simplest stable organic molecule. Chemical reactions spurred by the sun turn methane in Titan's atmosphere into more complicated hydrocarbons—including ethane, propane, and hydrogen cyanide. The process occurs in slow motion because Titan receives only a hundredth of the sunlight Earth gets. That makes the moon a time capsule that holds clues about how carbon compounds were created before life emerged on Earth and began pumping oxygen into the atmosphere. "You take Earth, add more atmosphere, move it away from the sun, slow down the rotation, and then change your chemistry by replacing water with methane," says Griffith.

For the first time the question of what happens in this kind of primordial organic soup is about to get answered. One of the biggest, most complicated and expensive spacecraft ever built, the $3 billion *Cassini* is on its way to study Saturn and includes a piggyback probe named *Huygens,* which is designed to investigate Titan. *Cassini-Huygens*'s voyage has been tediously long. It was launched five years ago, has finally passed Jupiter, and is now headed across 400 million miles of open space to a rendezvous with Titan in two years. Once there, during its third pass at Titan, three-ton *Cassini* will get 770 pounds lighter as it ejects *Huygens* into the 370-mile-deep atmosphere. *Huygens,* built by the European Space Agency, will then begin a drop that lasts 2½ hours. At 100 miles above the surface, *Huygens* will deploy the first of three parachutes. The heat shield will pop off; instruments will gather data about the chemical composition, temperature, pressure, and density of the atmosphere; a wind sensor will monitor gusts and updrafts; and electrodes will measure lightning strikes. Meanwhile, *Cassini* will upload data sent by *Huygens* and begin 42 more close passes at Titan.

Scientists hope that *Huygens* will pass through wispy clouds of methane gas on its way down. Griffith and her colleagues have used the United Kingdom Infrared Telescope atop Hawaii's Mauna Kea to study these clouds and found that they persist for a few hours and then disappear, presumably after dumping methane rain. A single drop of the oily stuff would measure a huge third of an inch across, but because Titan's atmosphere is so heavy and sluggish, it would fall approximately one-sixth as fast as rain on Earth—slow enough to dodge.

As *Huygens* continues its spiraling descent, Titan's enigmatic surface features should come into view. Athena Coustenis, a planetary scientist at the Paris-Meudon Observatory, will be watching to see whether the moon looks like her predictions. Using the Canada-France-Hawaii Telescope on top of Mauna Kea, she has picked out some bright spots of light that may be mountaintops. "Mountains would look bright to our telescope just because there is less atmosphere in the columns above them," she says. The spots are so bright that she speculates the mountains are up to 10 miles high and covered with something that reflects a lot of light. "What comes naturally to mind is snow," she says, perhaps flakes of methane and ethane.

Coustenis and other researchers have also isolated dark areas they think might be lakes. "Titan could be just like Earth, where you have high elevations with ice and lower areas with liquid," says Seran Gibbard, a planetary scientist at Lawrence Livermore National Laboratory. The liquid in the lakes might be a thick, dark slurry of ethane and other hydrocarbons.

Huygens is set to come down either just north or just south of the equator, and scientists don't know what it will land on. The northern area is in a fairly dark patch, which Lunine says raises the odds that the probe will come to rest in a rich patch of organics. The southern area is brighter but not as bright as the areas scientists think are mountains or plateaus. If the probe lands on an ocean or a lake, it is designed to float, make depth soundings, and figure out the composition of the liquid it's bobbing around in. In any case, it is likely to land on some sort of organic material. Lunine and others on the *Cassini-Huygens* science team calculate that a layer of hydrocarbons, perhaps half a mile deep, covers most of Titan. *Huygens* will be moving at only 15 miles per hour when it hits the surface. There are no landing legs or air bags, but researchers are holding out hope that the probe will not be destroyed on impact

'On Titan,' the late Carl Sagan once

PHOTOGRAPHS ON PREVIOUS PAGES: LEFT, COURTESY OF NASA; RIGHT, COURTESY OF ATHENA COUSTENIS ET AL., PARIS OBSERVATORY, FRANCE.

mused, 'organic matter is falling from the skies like manna from heaven'

and that, because it should still be hot from its descent through the atmosphere, it will melt its own little crater, allowing more time for an inventory of surface chemicals.

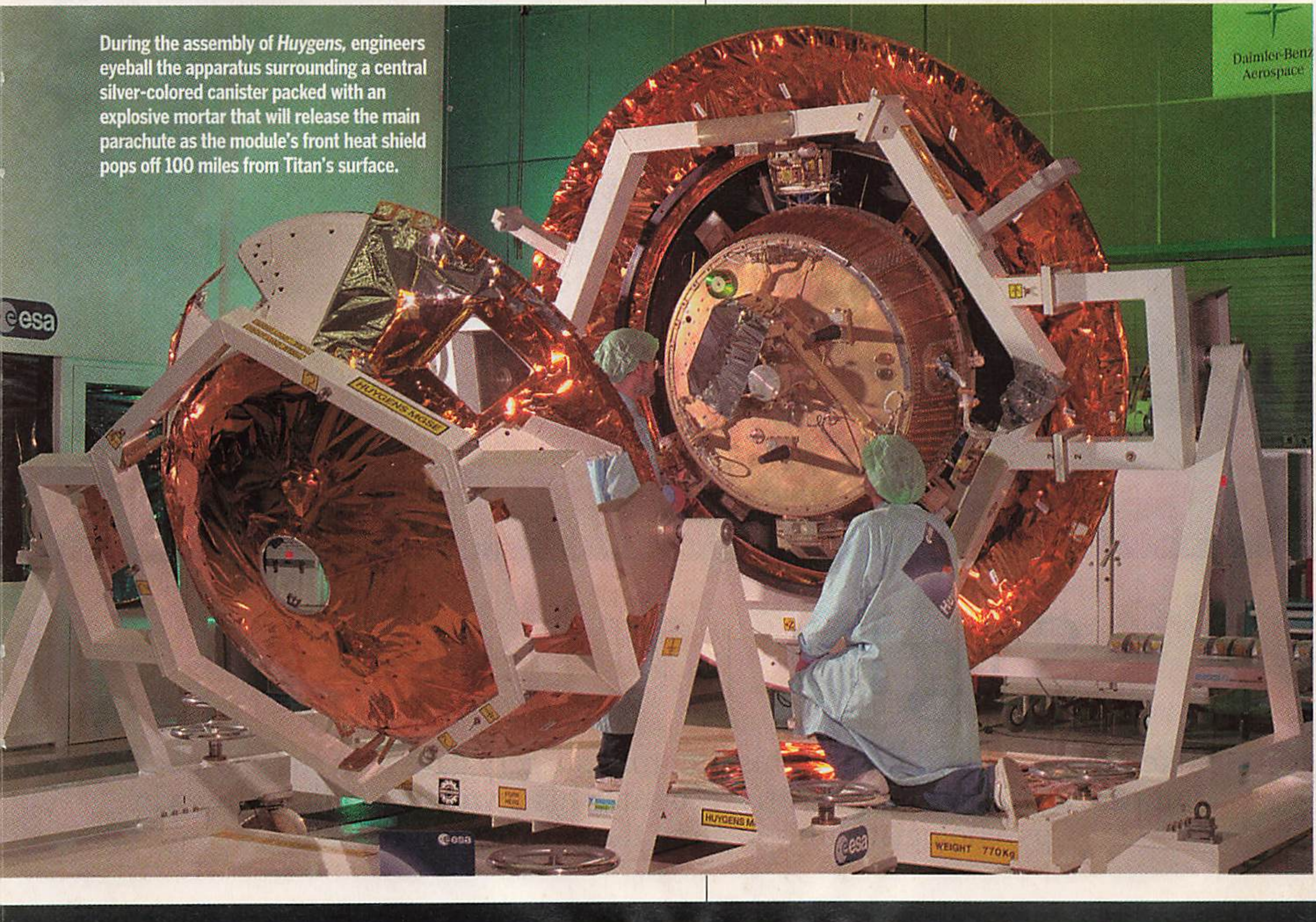
LIFE REQUIRES WATER, ENERGY, AND HYDROCARBONS, INCLUDING AMINO acids that some scientists speculate were ferried to Earth by asteroids. These ingredients may be combining now on Titan. "Organic molecules could have time to evolve where asteroid impacts have melted the ice in the crust into lakes of liquid water that could last for more than 1,000 years," Lunine says.

Even if *Huygens* can't identify every type of organic molecule on Titan, it should reveal whether dumb chemistry rules the roost or if something more complex is occurring. "If you look at certain meteorites, you see at least 70 amino acids, and their abundances decrease as they take more complex forms," says astrobiologist Chris Chyba of Stanford University and the SETI Institute. "But on Earth you find an incredible abundance of only 20 amino acids and extremely low amounts of the others, because life selects certain molecules."

For example, living things on Earth preferentially use molecules that are twisted into particular "handed" forms, rather than their mirror images. Lunine says: "We know that all life on Earth—every cell in our body, every bacterium—relies on left-handed amino acids and right-handed sugars. It's essential to how the molecules are put together. If we see signs of this on Titan, it means that some of the more difficult steps leading toward life have been solved."

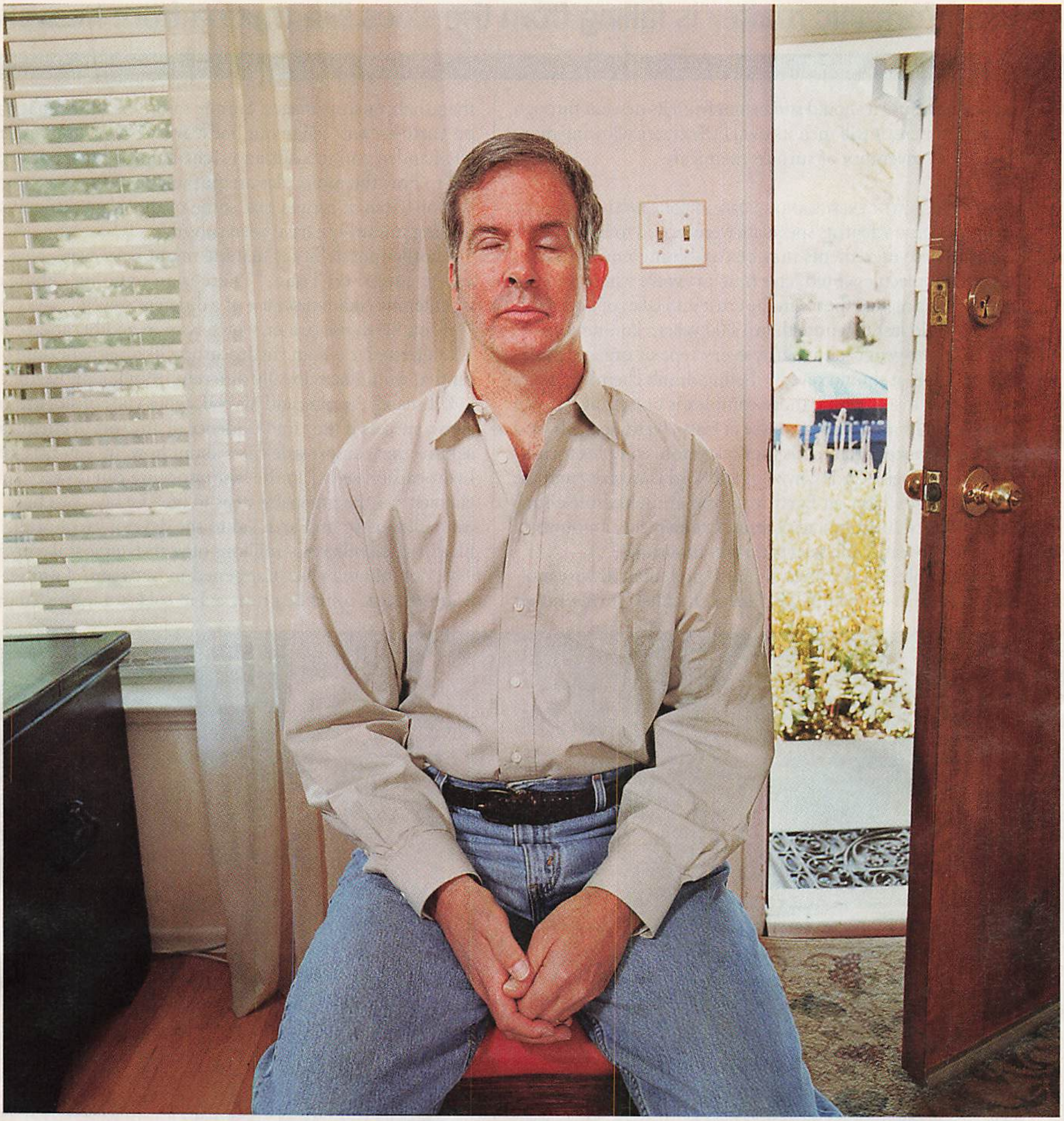
Another possibility is that life might have even charted an exotic course on Titan. "There is an ongoing debate over whether life could make use of a different solvent," says Chyba. "Life on Earth uses water, which is an incredibly good choice. The alternative is some hydrocarbon like methane. Life based on that would be radically different from life on Earth."

Ultimately, Lunine and his colleagues will consider the mission a success if they find evidence of any sort of chemical reactions that can provide clues about how life emerges from a hydrocarbon stew. "In the laboratory we can do very simple chemistry—the pre–baby steps to life," he says. But how such early chemistry on Earth led to the development of the first life-forms hundreds of millions of years later is still a mystery. "We don't know what happened in between," Lunine says. "Those stages could be preserved in cold storage on Titan." ☒



During the assembly of *Huygens*, engineers eyeball the apparatus surrounding a central silver-colored canister packed with an explosive mortar that will release the main parachute as the module's front heat shield pops off 100 miles from Titan's surface.

PHOTOGRAPH COURTESY OF ESA.



Sight | Unseen

Mike May was blind most of his life until surgery gave him his sight back. But two years later he still can't recognize his own wife. By learning why, psychologists are revealing the very origins of vision

MIKE MAY HOLDS THE WORLD SPEED RECORD for downhill skiing by a blind person. In his competitive days he would slalom down the steepest black-diamond slopes at 65 miles an hour, with a guide 10 feet ahead to shout "left" and "right." The directions were just obvious cues. The rest came from the feel of the wind racing against his cheeks and the sound of the guide's skis snicking over the snow. But May's days as a world-class blind athlete are behind him. He's no longer blind.

May lost his vision at the age of 3, when a jar of fuel for a miner's lantern exploded in his face. It destroyed his left eye and scarred the cornea of his right, but over the next 43 years he never let those disabilities slow him down. He played flag football in elementary school, soccer in college, and nearly any activity that didn't involve projectiles as an adult. He earned a master's degree in international affairs from Johns Hopkins, took a job with the CIA, and became the president and CEO of the Sendero Group, a company that makes talking Global Positioning Systems for the blind. Along the way, he found time to help develop the first laser turntable, marry, have two children, and buy a house in Davis, California. "Someone once asked me if I could have vision or fly to the moon, what would I choose," he once wrote. "No question—I would fly to the moon. Lots of people have sight, few have gone to the moon."

Then one November day in 1999, he came back to his senses. At St. Mary's Hospital in San Francisco, surgeon Daniel Goodman dropped a doughnut of corneal stem cells onto May's right eye (his left was too severely damaged to be repaired). The cells replaced scar tissue and rebuilt the ocular surface, preparing the eye for a corneal transplant. On March 7, 2000, when the wraps were removed, May got his first look at his wife, his children, and for the first time since he was a toddler, himself.

Sight restoration is a periodic miracle—both for its recipients and for the scientists who have the privilege of studying them. As early as the fifth century B.C., Egyptian surgeons used a needle to push their patients' cataract-covered lenses away from their pupils, affording them some degree of sight. More recently, in the late 1960s, surgeons learned to remove cataracts with ultrasound. The stem-cell surgery performed on May was developed in Japan and introduced in 1999. Since then hundreds of people have benefited from it. But of all those who have had their sight restored throughout history, only about 20 recorded cases were blind since childhood, and of those,

BY MICHAEL ABRAMS

PHOTOGRAPHY BY ALYSON ALIANO

A blind man who is suddenly given vision, Molyneux suggested,

most had less-than-perfect corneas after surgery. When Goodman peered into May's eye after the surgery, he saw a lens that ought to provide crystal-clear vision.

It doesn't—far from it. Pristine as his optical hardware is, May's brain has never been programmed to process the visual information it receives. May still travels with his dog, Josh, or taps the sidewalk with a cane, and refers to himself as "a blind man with vision." And that paradox fascinates Don MacLeod and Ione Fine, experimental psychologists at the University of California at San Diego. The speed with which babies learn to understand the world suggests that they're born with the ability to process some aspects of vision. But which aspects, exactly? What is learned and what is hardwired? During the past year and a half, Fine and MacLeod have put May through a battery of physical and psychological tests, including functional magnetic resonance imaging, or fMRI, which tracks blood flow in the brain. The results are opening the first clear view into how we learn to see.

MACLEOD'S LABORATORY AT THE UNIVERSITY IS A LABYRINTH OF FILING cabinets, optical equipment, and oddly placed desks. "It's well booby-trapped," he says, steering May toward the first of many tests one afternoon. "But May has an uncanny ability to navigate complicated arrangements." Tall and athletic, with features that look boyishly handsome despite his graying black hair, May would make a good James Bond if not for a few side effects of his blindness. Unlike the rest of his body, his eyelids haven't had a lifelong workout. Perpetually half closed, they lend a stoic blankness to his face that's relieved only by the occasional smile. He has yet to learn facial expressions.

Sitting obligingly in front of an ancient computer monitor, May watches as thick black-and-orange bars appear on the screen. MacLeod and Fine are testing his ability to see detail. His job is to adjust the contrast with a trackball until he can just see the bars. A click on a mouse brings up another set of bars, thinner than the last, and he plays around with those until he can see them too. Although his right eye ought to provide 20/20 vision, in reality it's closer to 20/500. Instead of discerning the letter *E* on an eye chart from 25 feet, May can see it only from two. In the past the blurred vision of people with restored sight was blamed on scar tissue from surgery. But stem-cell surgery leaves no scars. The signals are reaching May's brain, but they are not being interpreted very well.

More than 300 years ago, in a famous letter to the philosopher John Locke, the Irish thinker William Molyneux anticipated what May sees. A blind man who is suddenly given vision, Molyneux suggested, wouldn't be able to tell the difference between a cube and a sphere. Sight is one kind of perception and touch another; they can be linked only through experience.

The most dramatic proof of this theory came in an experi-

Functional magnetic resonance imaging, here being performed on graduate student Melissa Sáenz, tracks blood flow in the brain. UCSD researchers used this same technique at Stanford University, in collaboration with the Salk Institute, to chart Mike May's visual processing after his sight was restored.

wouldn't be able to tell the difference between a cube and a sphere

ment published in 1963 by Richard Held and Alan Hein, who were then professors at Brandeis University in Waltham, Massachusetts. Held and Hein raised two kittens in total darkness. But every so often they would place the kittens in separate baskets, suspend the baskets from a single circular track, and turn on the lights. Both baskets hung just above the floor, but one had holes for the kitten's legs to poke through; the other did not. The free-limbed cat ran in circles on the floor, pulling the other basket along behind it; the other kitten had no choice but to sit and watch. While the active kitten learned to see normally, the passive kitten stayed effectively blind: Its eyes could see, but its brain never learned to interpret the sensory input.

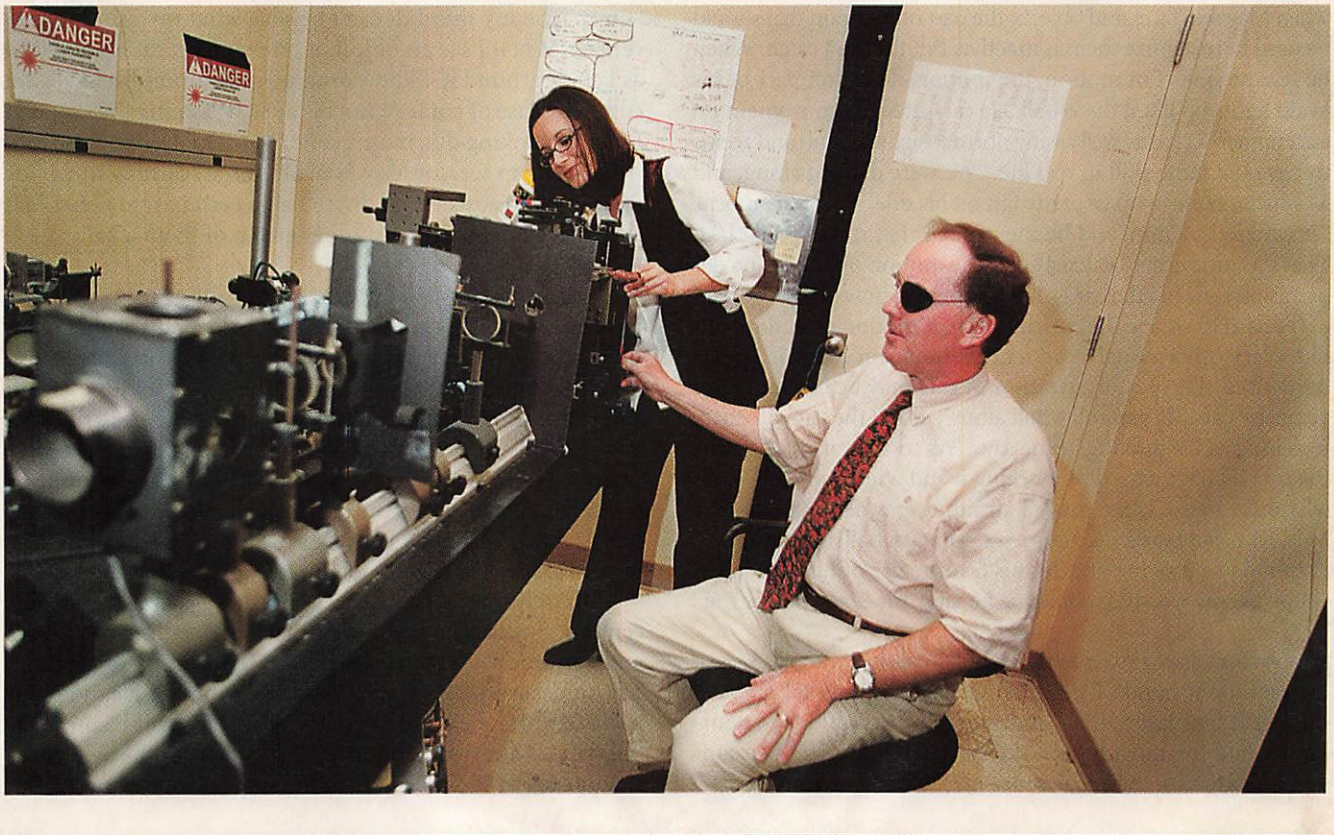
Held and Hein's experiment has never been duplicated. But in the past half century, studies of sight restoration, most notably by Oliver Sacks and Richard Gregory, have verified that some things can't be understood without experience. Objects, faces, depth—just about everything that helps us function in the world—are meaningless when a person who has never seen before gets sight. "Babies are born into a bright, buzzing confusion, but we can't ask them what it's like," Fine says. "In some ways talking to Mike May is like getting to talk to a 7-month-old."

IN THE FIRST MONTHS AFTER HIS SURGERY, MAY FULFILLED MOLYNEUX'S prediction: He couldn't distinguish a sphere from a cube. Since then his sight has improved, but only slightly. He has a better grasp of spheres and squares ("We've shown him an awful lot of them," Fine says), and with practice he can understand things he's seen again and again. But this is only a work-around: He's past the critical period for learning to recognize objects instantly.

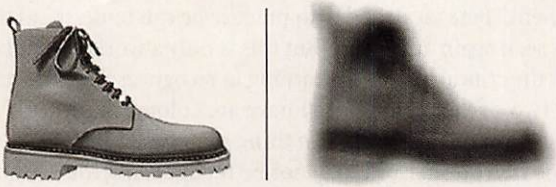
"Two of the major clues I have are color and context," May says. "When I see an orange thing on a basketball court, I assume it's round. But I may not be really seeing the roundness of it." Faces give him even more trouble. Although he has seen faces everywhere since the first day his vision was restored, they simply don't coalesce into recognizable people. Their expressions—their moods and personalities—elude him entirely. Even his wife is familiar to him only by the quality of her gait, the length of her hair, and the clothes she wears. "If a face has no hair and a fake moustache, we can still tell the gender," Fine says. "But he can't deal with it. The bit of the brain that does that isn't working."

The best proof of this can be seen in the basement, where MacLeod's interferometer sits. Designed to test the brain's ability to process visual information, the machine works by shining a split laser beam into a subject's eye. As the beams travel, their light waves interfere with each other, bypassing the optics of the cornea and projecting a pattern onto the retina. Most subjects who sit in front of the interferometer will see light and dark stripes, regardless of the quality of their optics. But when May opens his eyes to receive the beams, he sees nothing at all. →

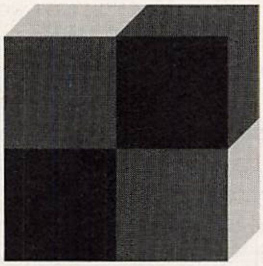
Ione Fine and Don MacLeod use this interferometer to shine a split laser beam into May's eyes to test his ability to process visual information. They also run the same test on themselves. "I spend a lot of my time down here," Fine says, "with an eye patch on and a bite bar in my mouth. It's disgusting . . . really old plastic."



Do You See What I See?



May ought to have 20/20 vision since his right eye was restored by stem-cell surgery and a corneal transplant. Instead, his vision is closer to 20/500—or about as blurry as the example to the right. "Basically, the results say that you can only get precise vision early in life at the critical period," Don MacLeod says. "We don't really know where May will end up, but he isn't approaching normal vision at a quick rate."



Right: A lifetime of blindness has left May insusceptible to visual illusions. Most people would say that the top of the dark cube is darker than the front of the light cube. To May they're the same exact shade. It's only when MacLeod explains the illusion that May can even see that squares are supposed to look three-dimensional.

The interferometer results are backed by fMRI scans, which track May's brain activity as it's occurring. The scans show that when May sees faces and objects, the part of his brain that should be used to recognize them is inactive. But there's a catch. When he sees an object in motion, the motion-detection part of his brain lights up like a disco ball. He can interpret movement on a computer screen as well as any normal-sighted adult and seems to have the same skill in real life. "We were driving along, and a minivan came up to us pretty fast on his side," Fine remembers. "It whizzed by him, and he mentioned that it was going fast. That's a complicated calculation. The motion on the retina depends on how big the car is, how close, and how fast it's going."

It's hard to escape the conclusion that motion detection, unlike every other visual experience aside from color, is largely hardwired. The best illustration of this may be offered, once again, by cats. "If you roll a ball along a floor, the cat will chase it as long as it's moving," Fine says. "As soon as it's stationary, the cat will have a hard time seeing it and will ignore it." That's why mice freeze when they're afraid. It may also explain why May, who can barely recognize a stationary ball, is pretty good at catching a moving one. It's his favorite use of his new sense. "I don't know who has more fun," he says, "my 8-year-old or me."

BLIND PEOPLE SPEND THEIR ENTIRE LIVES UNDERSTANDING THE WORLD through their hands. Their memories, their mental maps of the places they know, their understanding of Labradors, doorknobs, and the moguls on a ski slope are all tactile. The sudden introduction of a new sense can't alter that fundamental way of experiencing the universe. Instead, any new information gleaned from light is simply graphed onto the original, tactile map. "The old idea that there is one picture of the world on the surface of the cortex is way too simple," MacLeod says. "In fact, we have a couple dozen complete maps." For someone just learning how to merge all that information, this can make for a great deal of confusion. But it might also offer a richer, truer sense of the world than the one perceived by those of us who have never been blind.

Sitting in the lab one day, MacLeod, smirking like a schoolboy who's hatching a prank, slides a drawing across the table to May. On the paper are four cubes. The top right cube and the bottom left cube are dark; the other two are light. The drawing is shaded as if light were coming from above, so the tops of the squares are lighter than their fronts. This makes the top of the dark square the same shade as the front of the light square. Experience tells us that the top of the dark cube has been brightened by a hidden light, but it still seems darker than the front of a light cube. It's an illusion based on knowledge. Naturally, May doesn't fall for it.

"He's actually closer to reality," Fine says. "We once showed him two circles—a small one close to him and a larger one farther away. To you or me they would have appeared to be the same size. But when we asked, 'What's the apparent size?' he couldn't understand. He kept saying, 'I know it's bigger because it's far away.'" Similarly, May's tactile experience with hallways and highways tells him that their sides are parallel, so he simply can't perceive converging lines of perspective. "A hallway doesn't look like it closes in at all," he says. "I see the lines on either side of the path, but I don't really think of them as coming closer in the distance." He pauses to mull this over. "Or maybe my mind doesn't believe what my mind is perceiving. When I see an object, it doesn't look different to me as I circle around it. I know orange cones around vehicles are cones because of context, not because I'm seeing the shape. If I picture looking down on a cone, it still looks like a cone."

Learning to see, for May, is really about learning to fall for the same illusions we all do, to call a certain mass of colors and lines his son, to call another group of them a ball.

ONE APRIL MORNING, ONLY WEEKS AFTER HIS EYE SURGERY, MAY took his skis and his family up to the Kirkwood Mountain Resort in the Sierra Nevadas—a place he knew like the texture on the back of his hand. This was where he had first learned to ski and where he had later met his wife. The sun was out, the trees were green (greener than he'd imagined), and the slopes were surrounded by gorgeous cliffs (were they miles away or just a few hundred yards?). As the lift churned above, skiers in puffy parkas flitted by, popping into his field of vision. His wife, acting as a guide, had to remind him to stop gawking and ski.

With only one working eye, May already lacked depth perception. But he also had little experience reading the shades and contours of a landscape. Heading down the mountain, he could hardly distinguish shadows from people, poles, or rocks. At first, he tried to compute the lay of the land consciously: If a certain slope was being lit from the side and a shadow fell in such a way, then the slope must be convex. But

> Only a handful of adults have ever seen the world through the eyes of a newborn, and many who did came away wishing they were still blind

once he hit his first bump, he was tempted to close his eyes and ski the way he knew and loved.

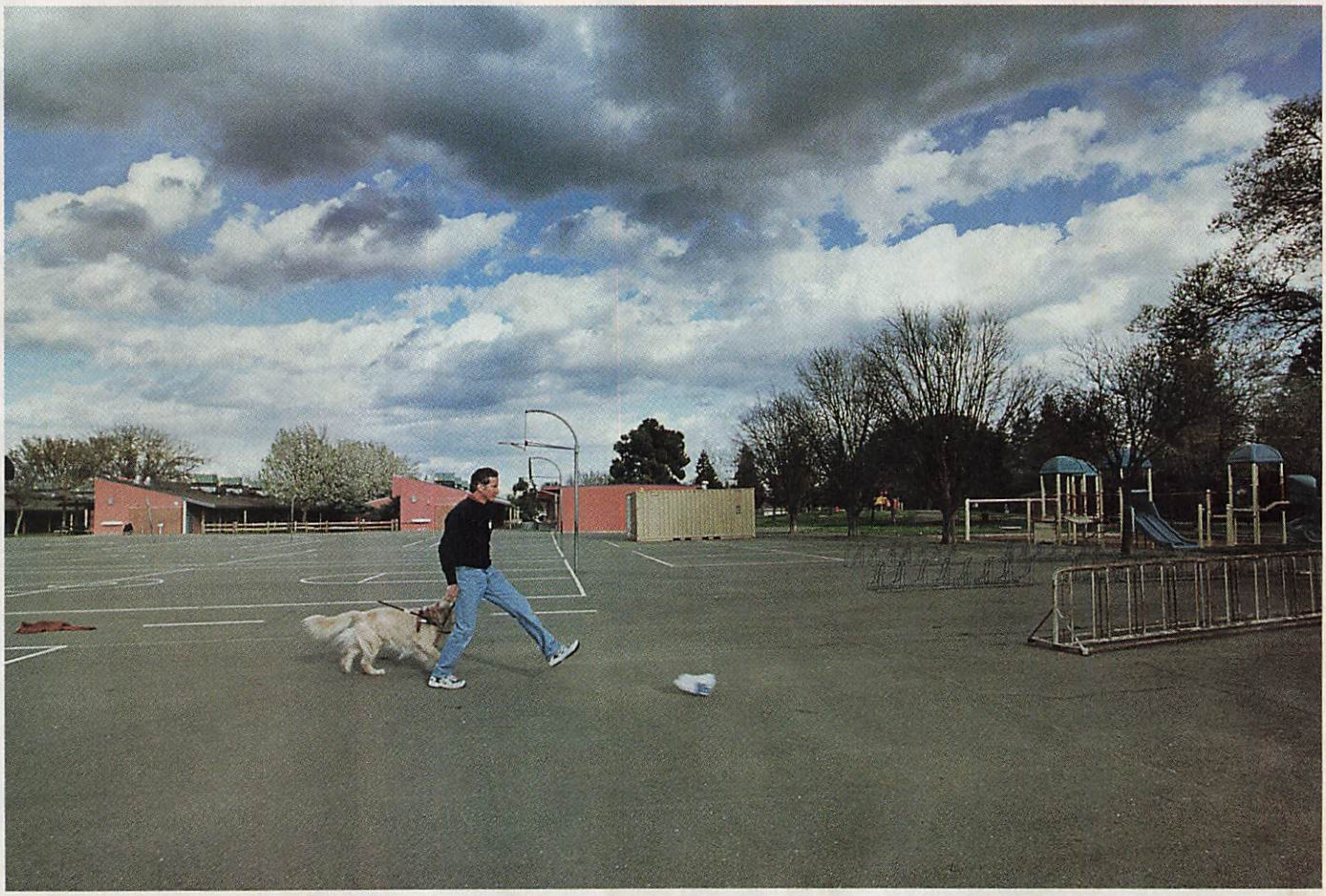
Only a handful of adults have ever seen the world through the eyes of a newborn, and many who did came away wishing they were still blind. Their family and friends had convinced them that vision would offer a miraculous new appreciation and understanding of the world. Instead, even the simplest actions—walking down stairs, crossing the street—became terrifyingly difficult. Dispirited and depressed, about a third of them reverted back to the world of the blind, preferring dark rooms and walking with their eyes shut.

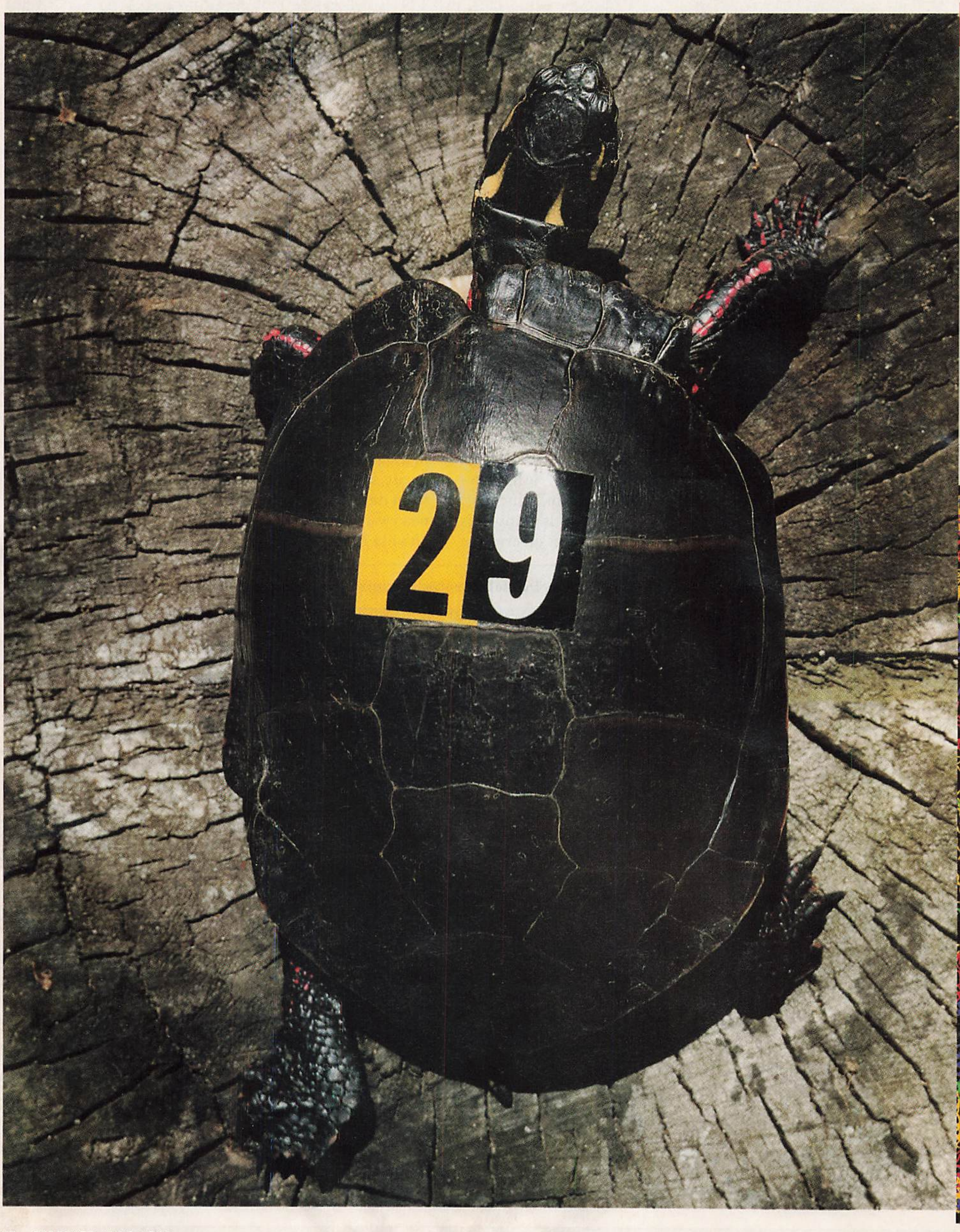
If May feels differently, it may be because his expectations were so low. For a man who used to enjoy windsurfing blind and alone, able more often than not to return to the pier from which he'd started, sight is just another adventure in a life of invigorating obstacles. Two years after his return to Kirkwood Mountain, May has learned to match what he sees on a ski slope with his repeated physical experience of it. "He has jury-rigged himself quite a functional little system," Fine says. "He knows that this kind of shadow makes this bump, this kind makes another." Instead of closing his eyes on even the easiest slopes, he can now negotiate moguls without a guide.

"People have this idea that it's so overwhelmingly practical to have sight," May says. "I say it's great from an entertainment point of view. I'm constantly looking for things that are unique to vision. Running and catching a ball is one of them—I've been chasing balls my whole life. Seeing the difference between the blue of my two sons' eyes is another. Or if you drop something, you can find it."

The gift of sight may seem most miraculous, in the end, to those who have never been blind. But May still finds things in the world to entrance him. Sitting in the passenger seat of Fine's car one day, with his dog, Josh, panting at his feet, he ignores the blue Pacific to the left, the towering, top-heavy eucalyptus trees lining the road like something out of Dr. Seuss. Instead, he gazes at the beam of sunlight filtering through the window onto his lap. "I can't believe the dust is just floating in the air like this," he says. Oceans and trees, Seussean or otherwise, he has known all his life through touch. But this glitter of dust, suspended in the bright La Jolla sun, is an entirely new awareness. He waves his hand through the sparkling beam. "It's like having little stars all around you." ☒

When May walks down the street, he can't recognize perspective lines, so he uses visual landmarks to keep his bearings. "I'm learning one frame at a time," he says.

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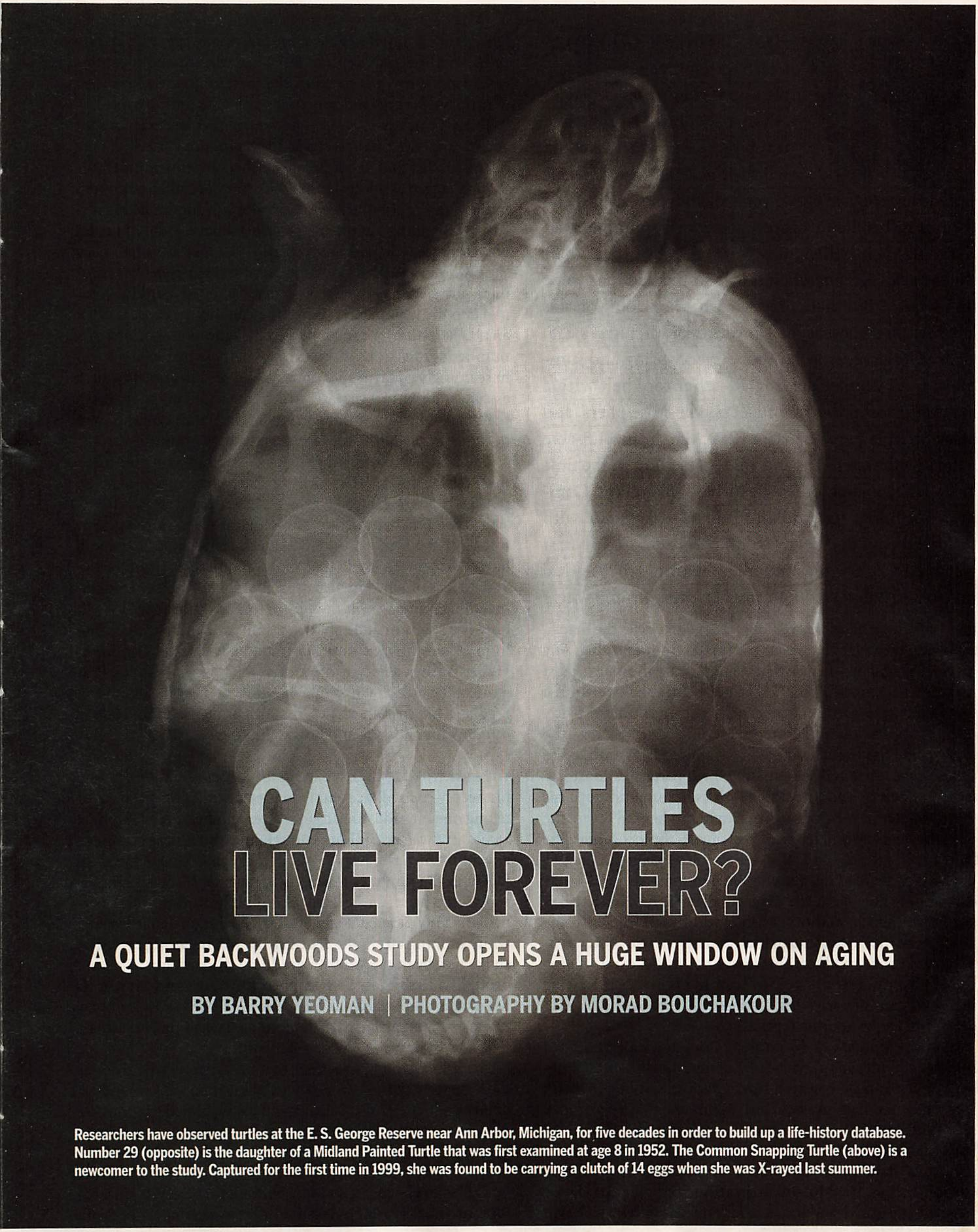


CAN TURTLES LIVE FOREVER?

A QUIET BACKWOODS STUDY OPENS A HUGE WINDOW ON AGING

BY BARRY YEOMAN | PHOTOGRAPHY BY MORAD BOUCHAKOUR

Researchers have observed turtles at the E. S. George Reserve near Ann Arbor, Michigan, for five decades in order to build up a life-history database. Number 29 (opposite) is the daughter of a Midland Painted Turtle that was first examined at age 8 in 1952. The Common Snapping Turtle (above) is a newcomer to the study. Captured for the first time in 1999, she was found to be carrying a clutch of 14 eggs when she was X-rayed last summer.

WHEN JUSTIN CONGDON WAS a teenager, he spent his days in the woods of northeastern Pennsylvania, shooting pheasants and trapping muskrats so he could sell their pelts for $4 apiece. He would have laughed had anyone told him he might spend the rest of his life in a forest preserve trapping turtles, X-raying their bellies, and painstakingly gluing their shells back together when they had the bad luck to be hit by cars. ¶ But that's precisely what he's doing on this late May afternoon at the University of Michigan's E. S. George Reserve, as he has done every spring and summer for 27 years. Carrying a leather tool belt with a makeshift rectal thermometer, needle-nose pliers, and black Sharpie pen, he patrols East Marsh, an 11.5-acre habitat with water lilies and wild irises. Most of the time he's on the lookout for female turtles—Blanding's, Common Snapping, and Midland Painted—abundant with fertilized eggs and ready to unload them on the first warm day. A low plastic fence separates the turtles' marshland habitat from the higher, drier ground where they build their nests. For 16 hours Congdon circles the marsh, following the fence that keeps the turtles from escaping. Any gravid—pregnant—female that wants to leave the marsh must make a small contribution to science before she's permitted to seek out a place to lay her eggs on the other side of the fence.

He spots a Midland Painted searching for a way past the barrier. She has the characteristic bright red trim around the edges of her shell and the intricate lined pattern, almost like a cave drawing, underneath. He picks her up and pops his thermometer in her cloaca, the chamber in her tail where the digestive, urinary, and reproductive organs come together. She flails her legs wildly and voids water onto Congdon's hands, but he gets his reading, a useful piece of information for understanding how the turtle manages the heat it needs to carry out reproduction and other biological functions. With the Sharpie, he marks her underside, or plastron, with body temperature, time, and location, tosses her into a camouflage-colored bag, and strides quickly back to his turtle-processing shed, a former military radar outpost that has become the border patrol for wandering reptiles.

In this primitive two-room shed, Congdon has conducted some of the most sophisticated life-history studies of long-lived vertebrates—research that could upend our theories about how animals grow old and might one day help unlock secrets of human longevity. For 49 years scientists have cataloged more than 12,000 turtles living on the reserve, compiling a huge database of individual reptiles. Each new capture has its shell marked for identification, and all animals are weighed, measured, and inspected for disease or injury. Gravid females are X-rayed to determine how many eggs they're carrying and how big they are. Nests are tracked and locations recorded. During peak season, the shed sometimes looks like a turtle traffic jam, and processing can take until 2 a.m.

Today's catch is a 16-year-old female that has been caught and X-rayed five times since she first reproduced in 1996. Some of the turtles that show up at the shed are much older; although tagged as adults in the 1950s, they are still healthy and fertile. They're also the key to Congdon's groundbreaking discovery: Blanding's and perhaps also Midland Painted turtles don't senesce—deteriorate physically—as they grow old. They simply don't age. And Congdon says the females actually produce more eggs as they grow older: "They're crankin' compared to the young ones." When they do die, the cause is often an attack—hit by a car or mauled by a raccoon—or one of a number of infectious diseases that kill these turtles at all ages in seemingly equal proportions. While certain ailments, such as cancer and heart disease, strike older humans more often than they do younger ones, Congdon's animals don't seem to become more vulnerable to disease as they grow older.

The findings are turning the discussion of aging in mammals upside down. "His work is a sharp challenge to a theory that has been taken at face value—that senescence is inevitable," says Caleb Finch, professor of biological sciences and gerontology at the University of Southern California. "Here you have a vertebrate turtle that shows no increase in mortality and no loss of reproductive capacity at ages where mammals, including humans, will shut down totally." Other species with long life spans include sharks, tarantulas, and rockfish, and human gerontologists are starting to pay close attention. As Huber Warner, associate director of the Biology of Aging Program at the National Institute of Aging, says, "If we knew what regulates life span in turtles, that might be useful in figuring out how humans age and how to intervene."

THE FIRST THING YOU NOTICE ABOUT JUSTIN CONGDON, OTHER THAN his deeply creased face and wild gray beard, is his passion for telling one bravado-tinged story after another, preferably over a cold Budweiser. Sit long enough and you'll hear about his adventure on a runaway logging truck while collecting lizard blood in the jungles of Mexico, an accident in which he almost lost a hand. Or he'll tell you about his run-in with a particularly testy Banded Water Snake that he spotted one evening while walking along the fence at the Michigan reserve. The snake had been tagged by a graduate student, but "I hadn't brought a flashlight. So I grabbed the snake and flipped its head back and pulled the tail up to read the ID. I didn't see, because it was getting dark, that the snake had pulled its head free, and it bit me in a wide-open eye."

The impression he creates is that of someone who lives far more happily outside polite society, someone who is simultaneously a meticulous biologist and a swashbuckling cowboy. Both images of himself seem to grow from the same impulse—the desire to dwell in unfettered wilderness, in places where people don't sip champagne. "A few years back, Gianni Versace was killed in Florida," says Mike Plummer, a biologist at Harding University in Searcy, Arkansas, who was eating dinner with

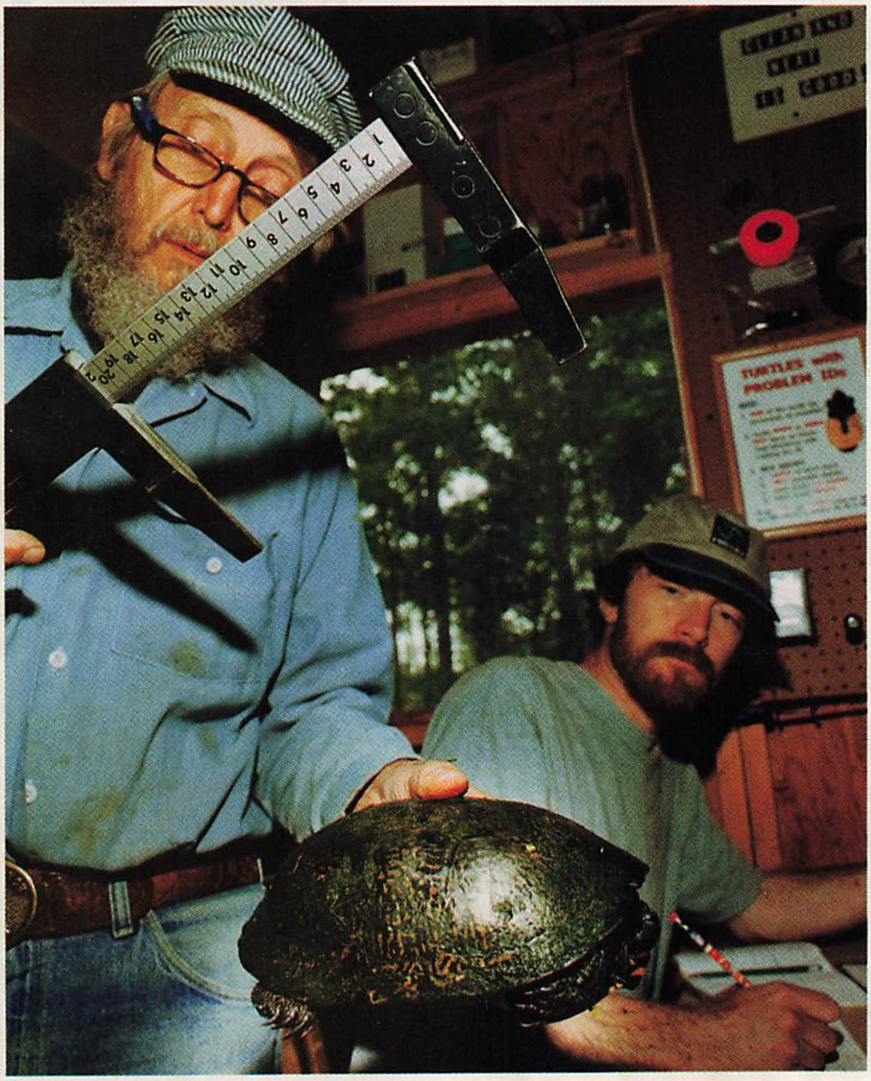
'You have a vertebrate turtle that shows no increase in mortality and no loss of reproductive capacity at ages where mammals, including humans, will shut down totally'

Congdon the night the fashion designer was murdered. "Somebody came out on the news and said, 'Tonight the world mourns for Versace.' Justin said, 'Can you believe that? The world mourns for the death of a guy who sews pants?' "

The two sides of Congdon's temperament—researcher and cowboy—fit naturally together, but they didn't always. Growing up in a military family, he had almost no interest in his studies and couldn't wait to come home from school to explore the swamps and woods near his house. Muskrats and water snakes held a fascination for him that classrooms and books did not. He assumed he would follow in his father's footsteps and pursue a career in the Navy, but three years of scrubbing toilets and cleaning guns on an aircraft carrier persuaded him to try college. The thought of returning to school scared him so much that as he drove to Victorville, California, to enroll in a junior college, he kept saying over and over to himself, "I hope I never get there."

Just one biology class convinced Congdon that he could make a living pursuing his childhood fascinations. At 26, while working toward a master's degree in biology, he moved into an abandoned copper and silver mine in the Mojave Desert, which he furnished with cast-off carpeting and a propane refrigerator in order to study how kangaroo rats and pocket mice use different desert habitats seasonally. For four days at a stretch, he'd trap intensively on one-quarter of his grid. The work was so intense that he had to stop and take a break, hiking the Providence and Granite Mountains; then he'd return to trap another quarter. At night he'd read by taillights salvaged from an abandoned car and hooked up to the battery of his Volkswagen bus. "I hated going near civilization," he says. "I promised my parents that I'd call them every time I went out for supplies, and I did. But there were two-week periods when they didn't hear from me."

Below: Justin Congdon and his chief assistant, Roy Nagle (right), measure larger shells such as that of this Blanding's Turtle with a caliper originally built for trees. For smaller shells, they use a digital caliper.



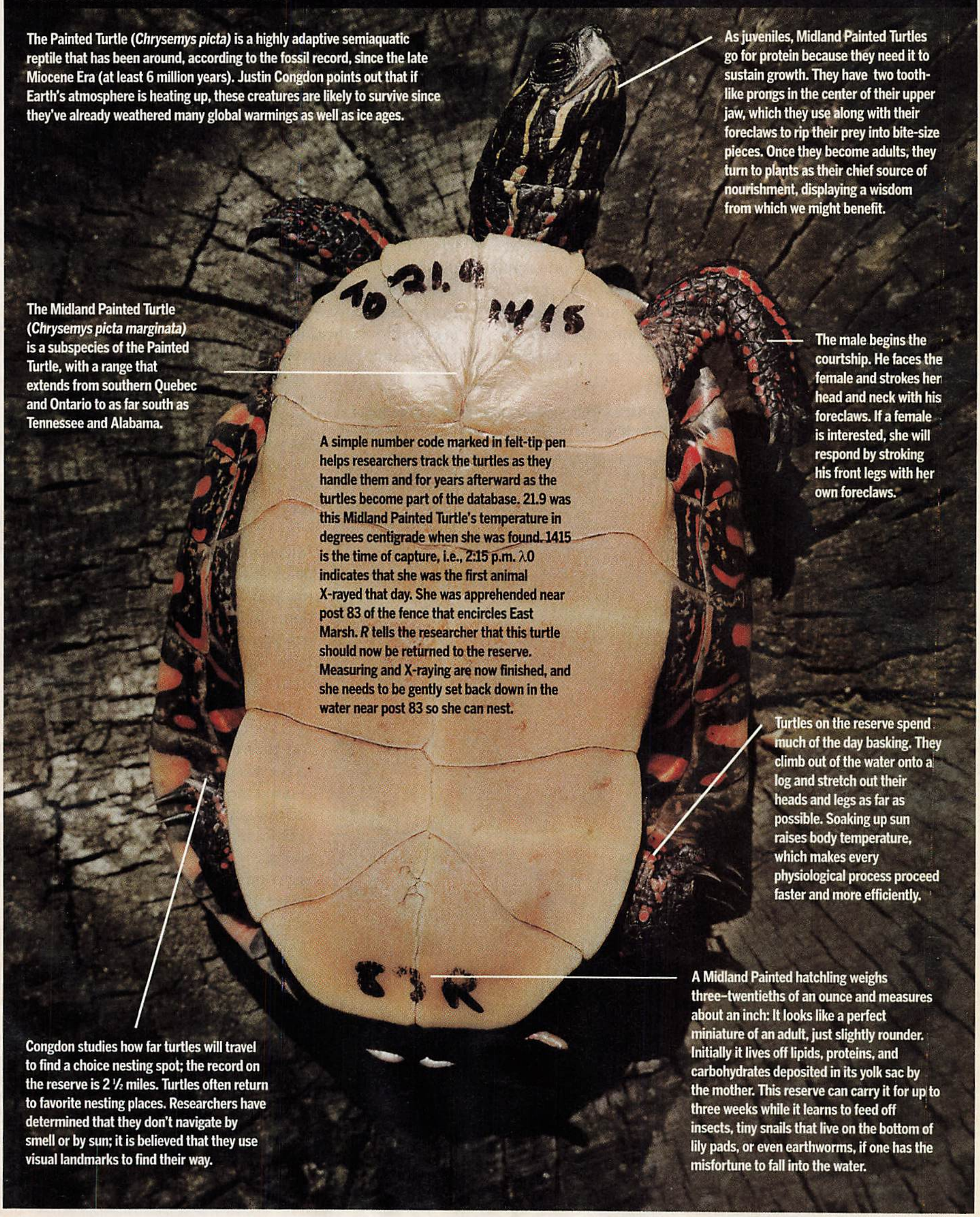
In 1975 his mentor at the University of Michigan, evolutionary ecologist and herpetologist Donald Tinkle, offered him a job on the E. S. George Reserve. The day Congdon and his wife arrived, carting all their belongings with them, Tinkle announced he was flying off to Utah to work on another study. "I said, 'You've got to be kidding,'" Congdon recalls. "I thought, 'My God, how am I going to handle this?' We left the truck half-unloaded, and Don and I went down to the swamp and checked traps, and he showed me the marking codes and where the equipment was, and then he left."

Once he had absorbed his new responsibilities, Congdon's days fell into a pleasant routine, canoeing in the wetlands to collect data on the residents. "I started trapping some marshes that hadn't been trapped, and we had a 100-turtle day when I went into East Marsh for the first time. At that point I think Don knew we were going to have a good study."

Tinkle died five years later, at 49. "I was devastated," Congdon says. "He was my mentor and academic hero." Just before his death, Tinkle called the National Science Foundation, announced he was terminally ill, and obtained permission for Congdon to run out the grant. The younger scientist vowed to oversee the project in a way that would honor his predecessor. "I

THE MIDLAND PAINTED TURTLE

The Painted Turtle (*Chrysemys picta*) is a highly adaptive semiaquatic reptile that has been around, according to the fossil record, since the late Miocene Era (at least 6 million years). Justin Congdon points out that if Earth's atmosphere is heating up, these creatures are likely to survive since they've already weathered many global warmings as well as ice ages.



As juveniles, Midland Painted Turtles go for protein because they need it to sustain growth. They have two tooth-like prongs in the center of their upper jaw, which they use along with their foreclaws to rip their prey into bite-size pieces. Once they become adults, they turn to plants as their chief source of nourishment, displaying a wisdom from which we might benefit.

The Midland Painted Turtle (*Chrysemys picta marginata*) is a subspecies of the Painted Turtle, with a range that extends from southern Quebec and Ontario to as far south as Tennessee and Alabama.

The male begins the courtship. He faces the female and strokes her head and neck with his foreclaws. If a female is interested, she will respond by stroking his front legs with her own foreclaws.

A simple number code marked in felt-tip pen helps researchers track the turtles as they handle them and for years afterward as the turtles become part of the database. 21.9 was this Midland Painted Turtle's temperature in degrees centigrade when she was found. 1415 is the time of capture, i.e., 2:15 p.m. λ0 indicates that she was the first animal X-rayed that day. She was apprehended near post 83 of the fence that encircles East Marsh. *R* tells the researcher that this turtle should now be returned to the reserve. Measuring and X-raying are now finished, and she needs to be gently set back down in the water near post 83 so she can nest.

Turtles on the reserve spend much of the day basking. They climb out of the water onto a log and stretch out their heads and legs as far as possible. Soaking up sun raises body temperature, which makes every physiological process proceed faster and more efficiently.

A Midland Painted hatchling weighs three-twentieths of an ounce and measures about an inch: It looks like a perfect miniature of an adult, just slightly rounder. Initially it lives off lipids, proteins, and carbohydrates deposited in its yolk sac by the mother. This reserve can carry it for up to three weeks while it learns to feed off insects, tiny snails that live on the bottom of lily pads, or even earthworms, if one has the misfortune to fall into the water.

Congdon studies how far turtles will travel to find a choice nesting spot; the record on the reserve is 2 ½ miles. Turtles often return to favorite nesting places. Researchers have determined that they don't navigate by smell or by sun; it is believed that they use visual landmarks to find their way.

wanted it to be run as good as it had been run, or better," he says. "I couldn't have had it any other way."

While crunching his data in the mid-1980s, Congdon made a startling discovery: The oldest female Blanding's Turtles—more than 50 years old—had more egg clutches than younger ones, as well as more eggs per clutch. Not only that, they died at a lower rate too. "What did I do wrong?" Congdon remembers thinking to himself. "Did I make a mistake? Did I analyze it incorrectly?" He knew that adult turtles kept growing throughout their lives, and so he wondered whether the true variable might be body size rather than age. Once he ran the numbers again, controlling for body size, he was astonished to find that he got nearly identical results.

At first, he didn't write up the findings. There was little or no conversation among gerontologists about nonhuman aging models. "I just couldn't get anybody interested in what I was doing," he says. So he resolved to bide his time, figuring that the more data he collected, the stronger his evidence would be.

AS HUMANS SENESCE, ARTERIES HARDEN, EYESIGHT DETERIORATES, vital organs lose capacity, reproduction stops, and the probability of death increases. For us, this progression makes evolutionary sense: Since we spend almost two decades raising children, it behooves us to finish producing them while we're still young. Our genes favor early childbearing; they also ensure that we'll be around long enough to raise our kids.

It also behooves creatures like mice and rats to have babies early in their lives but for a different reason: If they don't, they might get eaten before they reproduce. "Even if a mouse was immortal as far as physiological death, a predator would still get it within three or four years," says Whit Gibbons, an ecologist at the Savannah River Ecology Laboratory in Aiken, South Carolina, the facility where Congdon works during the part of the year that he's not in Michigan. "Therefore, their genes operate very well at the early stages of their lives. There's no sense having a gene in a mouse that's going to work in 10 years, because there's no way those genes will be passed on."

And mice are among a group of short-lived animals, which includes worms, lizards, and fruit flies, that scientists have traditionally used to study aging. With short-lived animals, "you can walk away from a project within three or four years, and you've got a lot of data, and you can make a big impression on your colleagues," says Ronald Nussbaum, a zoologist at the University of Michigan. Under such pressures, turtles are hardly the research subject of choice.

Why don't turtles operate like mice? One reason is their shell, which makes them less vulnerable to predators. At the same time, because they spend much of their early years developing their shells, they delay sexual maturity. Because turtles begin reproducing so late, and the vast majority of their young don't survive, evolution favored those individuals that were able to keep pumping out eggs. (See "Save the Grown-ups if You Want Babies" on this page.)

With the Blanding's Turtles in particular, not only are the old females still fertile, they're often more productive and have a higher survival rate than their daughters and granddaughters. Congdon's theory: Age brings wisdom, even in reptiles. "Blanding's Turtles know a lot about the landscape that they live in," Congdon says. "I'm not just talking about the immediate

SAVE THE GROWN-UPS IF YOU WANT BABIES

When we think of turtle conservation, we think of "head start" programs, in which nests are protected from predators and hatchlings are raised in captivity until the animals are old enough to survive in the wild. Meanwhile, adults are harvested on a regular basis, for the pet trade and for their supposed medicinal value. Justin Congdon's research is making a lot of people see that this scenario may be upside down: Hatchlings need protection, but adults need it even more.

"If you're interested in conserving long-lived species, what is your best strategy?" asks zoologist Ronald Nussbaum. "Most of the turtles' mortality occurs in the first year. Most of the eggs never make it. If a turtle produces 1,000 eggs, 998 of them can die as long as two of them, one male and one female, survive to replace her. So what would a conservationist do with this information? Well, you would make sure the adults survive and not worry too much about the nests and the eggs."

There's a reason wildlife managers haven't thought in those terms: Most of the animals we try to protect, such as deer, rabbits, and quail, are relatively short-lived. "With deer, you can eliminate 50 percent of the population, and two to three years later, you're back to where you were," says ecologist Whit Gibbons. "With turtles, they won't be anywhere near where they were. It takes so long for them to reach maturity that once you have an adult, you have a valuable commodity." Gibbons says protecting the adults makes sense for other long-lived species too. "This has immediate application—for whales, for elephants, for polar bears—for animals that live a long time and can't sustain the cropping they get." *—B. Y.*

After this Common Snapping Turtle was struck by a car, Justin Congdon determined that her back was broken, and so he had to shoot her to put her out of her misery. Although his team harvested the 30 eggs she was carrying, carefully built a nest for them in a promising spot, and covered that nest with a cage, predators managed to find and eat the eggs anyway.

'When you dissect a turtle's brain, you just go, 'Boy, there is not a lot of room in there for a lot of thought.' I mean, they are tiny, tiny brains. But I think these turtles are way smarter than we give them credit for'

landscape. We have animals that travel four kilometers [2½ miles] to nest. Do they know where they are when they are four kilometers away from where they started out? Yes. Did they have some innate, built-in map? No, they learned that route over years and years. So if a female goes to a place and it is not a successful nesting site, the old ones know where to find the next-best place better than the young ones. When you make it to your sixties with no doctors, you are the best of the best. Certainly, you can get run over by a mower. But maybe older females have a slight edge in avoiding risk."

He knows this is hard for many people to believe. "When you dissect a turtle's brain, you just go, 'Boy, there is not a lot of room in there for a lot of thought.' I mean, they are tiny, tiny brains. But I think these turtles are way smarter than we give them credit for." When Congdon retires and has enough time, he'd like to "train turtles to see how much they can learn. I think they could learn a lot."

While Congdon is developing life-history data on individual captures, other researchers are trying to get a better grasp on why the animals resist senescence. "The turtles are vertebrates, so they're reasonably closely related to us," says Steven Austad, professor of biology at the University of Idaho. "To the extent that, on a cellular level, these turtles show resistance to the stresses that damage human cells, they might have something to teach us."

James Christiansen, professor of biology at Drake University in Des Moines, is studying how telomeres, the simple, nongenetic DNA sequences that sheathe the ends of chromosomes, function in reptiles. Each time a healthy human cell divides, it loses a little bit of the telomere, until the strands are too short to protect the chromosomes. At that point the DNA in a cell begins to break down, which triggers senescence and death. Human cancer cells go off the program, producing an enzyme called telomerase that stops the shortening and renders the malignant cells immortal.

Turtles seem to follow a different pattern. "Even though many species live in some of our most polluted environments," Christiansen says, "they avoid cancer." Early results of his study suggest that some reptiles may receive a short burst of telomerase early in life, which makes healthy cells rather than cancerous ones immortal. If this proves to be the case, he says, the human implications may be dazzling. "If we could do that with humans shortly after birth, before the mutations have a chance to creep in," he says, "we could potentially add a hundred years to the human life span."

At 61, Congdon is increasingly aware of his own age. "I feel it," he says. "I don't think a lot about it. I feel it in terms of not being able to go and go and go without paying. I smile when the old Blanding's ladies look at me, and I imagine them saying, 'OK, go ahead, bother me today, but I'm going to outlive you.'" Congdon also fears the turtles will outlive the Michigan study. He plans to return to the reserve for five more summers—but will there be anyone to take over after he retires? "I have been told how valuable the research is," he says. "I've been told how a number of people want my data. I have yet to be told, 'I want the work.' So I don't have anybody on the horizon."

Today, though, he has more pressing concerns, like the fact that the late-spring chill seems to be stopping the turtles from building nests. About a half hour ago, he airlifted a 19-year-old female, tagged with a large number 5, over the East Marsh fence to build her nest, but he's concerned about the cloud cover and approaching cold. "She'll either commit really quick, or she won't," he says. "When the temperature goes down, all the biological processes—strength, muscle coordination, ability to export oxygen to the legs—go down." No. 5 makes her way up the side of an old gravel pit, finds her spot, and starts digging, but then hits a root and abandons the unfinished nest. She slowly inches farther up the hill, but the air has cooled noticeably. She gives up.

Back at the turtle shed, Congdon hears better news. Jason Sweas, his undergraduate assistant from the University of Michigan, has witnessed the first successful nesting of the season, on a lawn near the entrance gate. For an hour he watched as a Midlands Painted Turtle lowered her back end into the hole, laid her eggs, then spent an eternity covering them. She stretched one hind leg as far as it would go, then the other, with each stroke pulling some more soil back over the nest until her efforts were almost invisible. When she was finished, Sweas captured her and carried her to the shed.

He also brought a young male he had spied lumbering around with his shell cracked after he was hit by a car. "The spine's not broken," Congdon notes, so he cuts a four-inch strip of black electrical tape, applies it to the broken carapace, then spreads an adhesive over the tape. "The epoxy will hold it together until the bone grows back. Then it will fall off," he explains. "My guess is that we'll see this guy, with a slightly damaged carapace, years from now. I guess, technically, we shouldn't do this stuff. But I don't think we've changed the demography in any measurable way. If I could measure that accurately, I'd be a very happy guy."

It's time to think about knocking off work and having a beer. The successful nester and the injured male will live in Congdon's utility-room sink overnight and be returned to their swamp home in the morning. Before settling in for the evening, though, Congdon walks East Marsh one last time. He releases No. 5, and she swims back into the marsh, presumably to lay her eggs another day. Congdon watches her as she paddles through the water. Despite his insistence that he has no emotional attachment to his subjects, there's a look in his eyes that conveys the gruff affection he has developed for the critters.

Verbally, though, he concedes nothing. "Another day," he says simply. "Another turtle." ☒

Humans and raccoons are the two greatest threats to the survival of Midland Painted Turtles and their offspring. Raccoons, however, eat turtle eggs only to nourish themselves—people run over turtles, shoot them, turn them into pets, destroy their habitats, and assault them with pesticides.

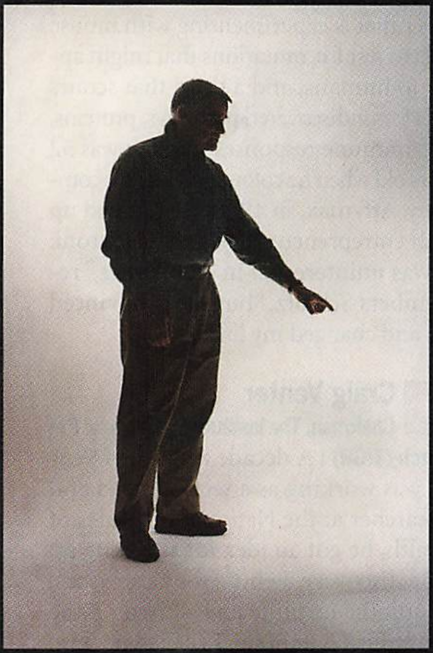
→ BY DAVID EWING DUNCAN PHOTOGRAPHY BY KAI WIECHMANN

20

Biotech Geniuses to Watch

Will biologists ever work exclusively at universities again?

THE EARTH IS MOVING UNDER THE WORLDS OF ACADEMIA, technology, and biology. Chemists, geneticists, and neuroscientists are leaving their cozy university labs to become executives of heavily endowed biotech start-up companies. Entrepreneurs who once brewed beer are CEOs of drug companies. Technologists and engineers without science degrees are solving the riddles of human genomics and proteomics. Think Niels Bohr and Albert Einstein with stock options. Think Henry Ford and Thomas Edison cooking up drugs. Traditional demarcations between biology and commerce, science and technology, advisers and inventors, business folk and ivory-tower researchers have dissolved. ¶ They nurture visions of a future as enticing as our human imaginations can bear: Yes, they insist, we really will conquer cancer, see paraplegics walk again, grow new skin for burn patients, and live to be 300. ¶ Most of the visionaries on this list remain obscure, but that is likely to be temporary. All have soared to superstar status within the science industry, which went white hot after the announcement two years ago that the human genome had been decoded. Since January 1, 2000, investors have pumped $59 billion into the hands of such people. No one is quite certain how many of their promises will come true or what unknown perils may await us as we tinker with the basic building blocks of life. But for these 20 geniuses, the biotech revolution is under way, and none are looking backward as they transform cash, moxie, and imagination into the drugs and treatments of our dreams. →



↑ **4** What biologist abandoned academia to found an independent research institute based on a business model?

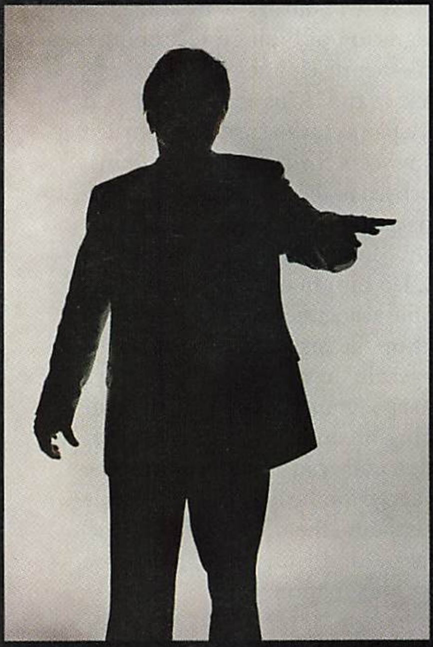
↑ **7** Will this Rockefeller University cell biologist eventually leave academia to help men regrow their missing hair?

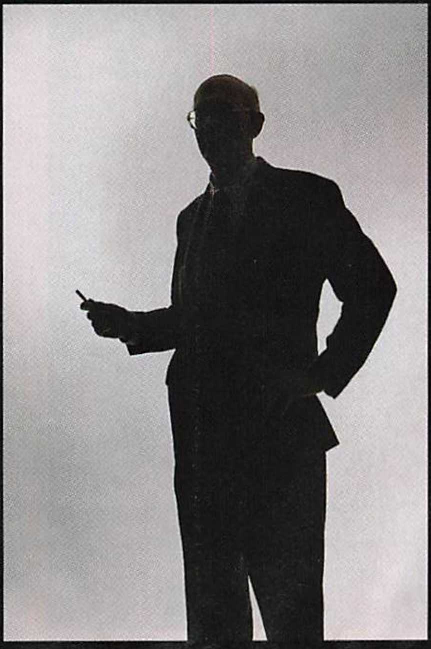
↑ **8** What former Harvard business professor became lead author on the historic paper that mapped the human genome?

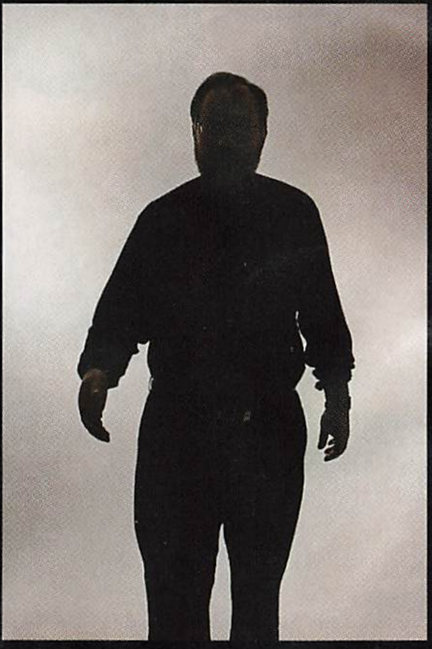
12 What former doughnut-shop owner is running a hot biotech company with a market cap in excess of a billion dollars? ↓

17 What Harvard chemistry professor and winner of the National Medal of Science tinkers with self-assembling molecules? ↓

18 What vice president of the Howard Hughes Medical Institute thanks a tiny insect for much of his success? ↓







1 Joshua Lederberg

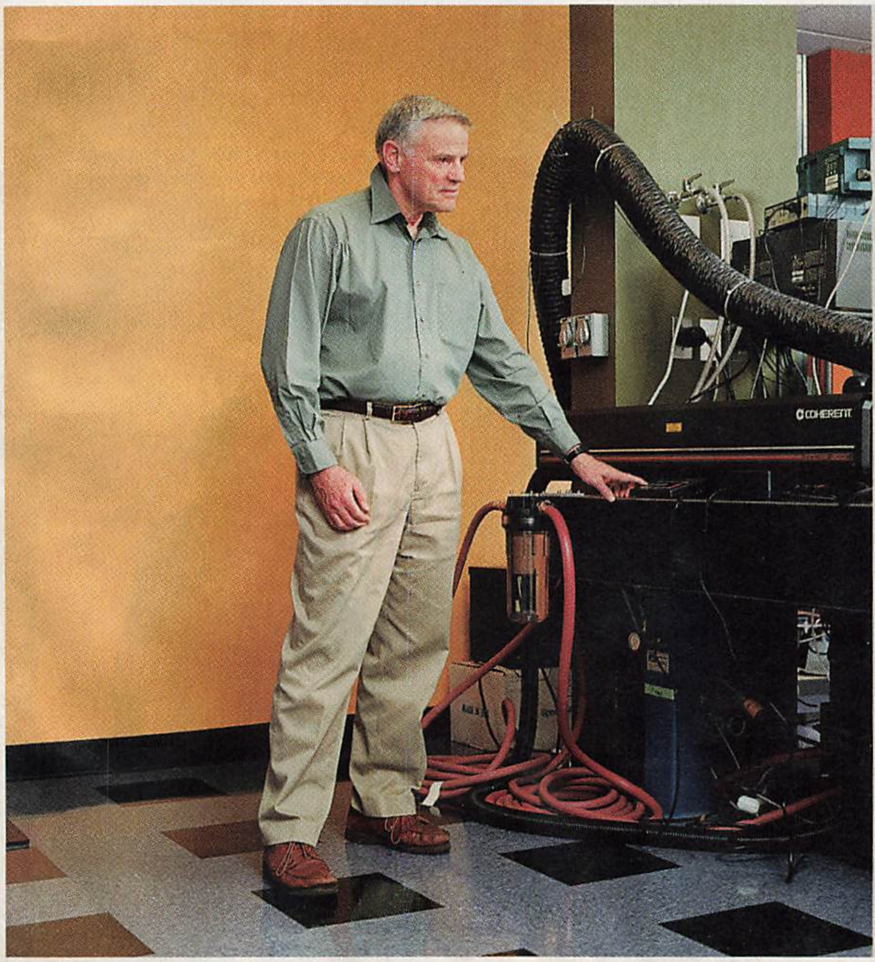
Professor Emeritus of Molecular Genetics and Informatics, Rockefeller University | Although he is passionate about the possibility of life elsewhere in the universe and considered a trailblazer in artificial intelligence, knowledge-based computer systems, and emerging infectious diseases, Lederberg's overwhelming interest is still focused on the subject that won him a Nobel Prize in 1958—bacteria. Lederberg's Nobel was based on his discovery of recombination in bacteria. His work in identifying the genetic structure and cell functions of bacteria has become central to a biotech industry that he helped found as an adviser to companies such as Affymetrix. "Right now, I'm looking to see how fast bugs grow," he says. "What are the limits to how much a cell can replicate?" That information is crucial to figuring out how to shut down rapid cell growth in cancer cells. He is also a member of the U.S. Defense Science Board, an important forum in the wake of September 11.

2 Peter Schultz

Director, Novartis Research Foundation's Genomics Institute | In 1999 Schultz founded Novartis's Genomics Institute in La Jolla, California. There, 220 researchers peruse everything from nanotechnology to learning and memory. His favorite question: Why did life settle on four DNA bases—represented by the letters A, C, G, and T—and 20 amino acids? To find out, Schultz and his colleagues have invented 80 new amino acids. They also began experimenting with a bioengineered bacterium that contains unnatural amino acids. "You could create powerful new proteins," he says, such as proteins with new side chains that kill tumor cells. Blending business and research, Novartis has spun off three new companies: one that hopes to unravel the structure of previously unmapped proteins, another that is experimenting with mouse cells to test for mutations that might apply to humans, and a third that scours cells for undiscovered pathways, proteins, and immune responses. Schultz was 32 years old when he cofounded his first company, Affymax, in 1988. He hooked up with entrepreneur Alejandro Zaffaroni. "I was uninterested in companies," remembers Schultz, "but Alex convinced me and changed my life."

3 Craig Venter

Chairman, The Institute for Genomic Research (TIGR) | A decade ago, when Venter was working as a section head and researcher at the National Institutes of Health, he got an idea for speeding up gene discovery. Rebuffed by superiors, he quit the institute and started up the nonprofit TIGR in Rockville, Maryland. In 1998 he founded the for-profit Celera. Within months it became obvious that Venter's rapid-sequencing technol-



4 Leroy Hood

President and Director, Institute for Systems Biology | When Hood was a young instructor at the California Institute of Technology, the chairman of the biology department asked him to stop teaching technology and stick to biology. He refused, quit Caltech, and eventually popularized the term *systems biology* to describe the integration of biology, technology, and other disciplines. The synthesis stuck: In the 1970s and 1980s, Hood was a pioneer who created automated sequencers for DNA and proteins, which led to the discovery of key proteins and chemical structures in the body. More impatience with academia led him to ditch another high-profile academic position in 1999 to start up the Institute for Systems Biology. He describes the innovative firm as a "grand experiment" in combining business methods with research and academic freedom. "The challenge for the future is with whole systems and theories of integration," he says, "and with being free to use your imagination."

ogy would win the race to decode the human genome. In June 2000 Venter stood in the White House beside his rival, Francis Collins, director of the NIH's genome project, as President Bill Clinton announced a compromise victory, declaring that Celera and the NIH had nearly completed decoding the genome. Since then the commercial promise of the genome has become muddled. The NIH posted a free version of the genome online, and investors realized that accumulating genetic data may be less lucrative than discovering new drugs based on the knowledge. Venter subsequently tried to reshape Celera into a drug-discovery company, then resigned in January. A week before his departure, he said he believed that the next wave of biotechnology will be personalized medicine in which massive computing power will be used to tailor treatments to an individual's own genetic map.

5 William Haseltine

CEO, Human Genome Sciences | A prominent cancer and AIDS researcher at Harvard's Dana-Farber Cancer Institute and the Harvard Medical School for 17 years, Haseltine made the jump from lab to business suite in 1992, when he founded Human Genome Sciences in Rockville, Maryland, just up the road from rival Craig Venter's headquarters at Celera. Haseltine's company now has a market capitalization of $3 billion and seven drugs in clinical trials, including treatments for growth hormone deficiency, hepatitis C, and venous ulcers. Hundreds more drug targets are in the company's plans. But the 57-year-old Haseltine's passion has turned to "regenerative medicine," a term he claims as his own. "It starts with the very simple notion that our bodies are machines that either become worn or broken, and there's an age-old desire to repair or replace those worn and broken parts. A number of avenues will allow us to do that." He envisions a medical future in which human tissues will routinely be used to replace aging organs.

6 Stuart Schreiber

Chair of Chemistry and Chemical Biology, Harvard University | In 1973 he had already planned to drop out of the University of Virginia to become a carpenter. "On a lark, I went to a chemistry class," he says, "and it seemed beautiful to me. It opened a window on a whole new world." Now a professor of chemistry and chemical biology at Harvard, Schreiber is opening a few windows of his own synthesizing small molecules that can be used to tweak proteins and protein pathways in cells. These are the mechanisms that control everything from immune response to memory. In the 1980s Schreiber created small molecules that stimulate mechanisms in the body's immune response system, leading to the discovery of a signaling network of proteins and receptors

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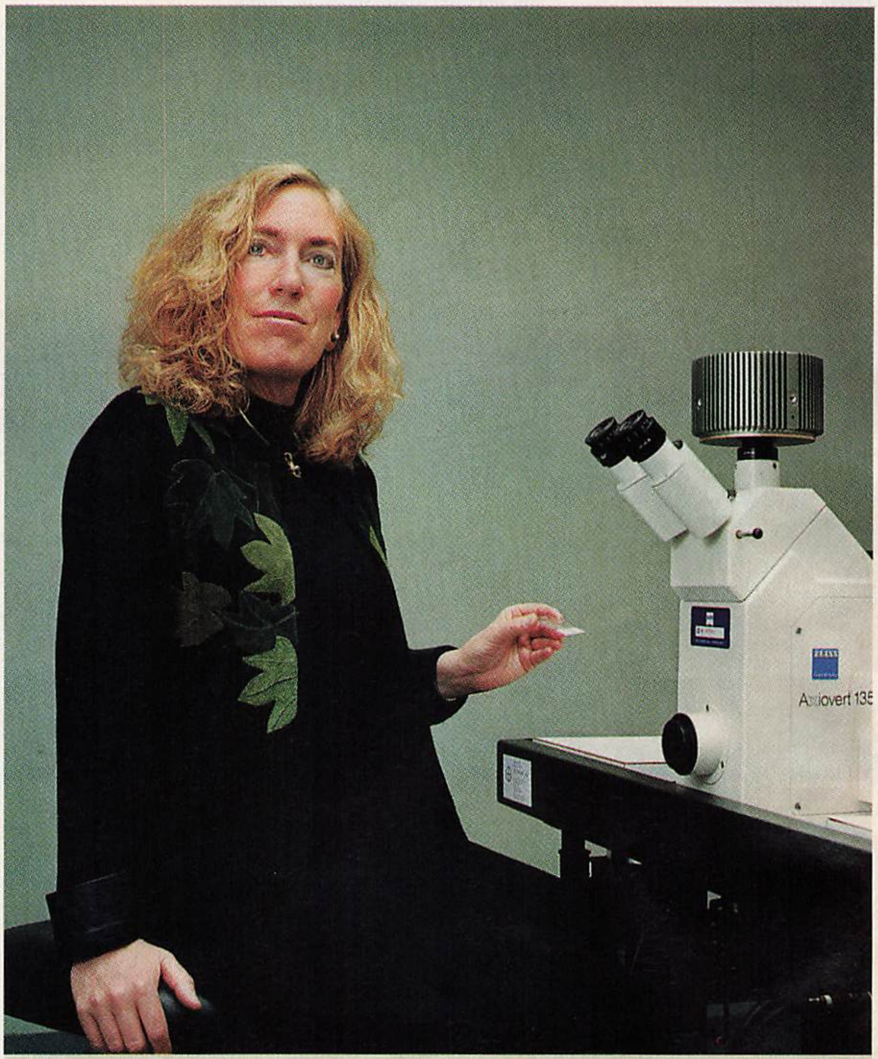

7 Elaine Fuchs

Head of the Laboratory for Mammalian Cell Biology and Development, Rockefeller University | Fuchs recently discovered how to induce hair growth by working with a protein that instructs embryonic skin cells to become hair follicles. She tweaked the stem cells of mice to make them extra furry. "Skin has been looked at very closely for years by dermatologists—every blemish, every permutation—because it's all exposed, unlike other organs," she says. "This information can be linked with genetics." Fuchs is exploring proteins that provide strength to skin diseases, others that cause blistering skin, and those involved in carcinomas. She is reluctant to go commercial but suspects she may anyway. "You can't stop it," she says. "It's how research is transferred into products for people."

crucial not only for immune functions but also for heart development and the acquisition of memory in the hippocampus. He uses computers and specially designed molecules that work as probes to study proteins and other natural molecules, hoping to map the inner genetic workings of the body. Once that infrastructure is understood, he says, scientists will know which particular genetic system does what, and "that's when the exciting part begins."

8 Eric Lander

Director, Whitehead Institute/Massachusetts Institute of Technology Center for Genome Research | Back in 1981, when it took geneticists a year or more to identify just a single gene, Lander was a 24-year-old Rhodes scholar with a fresh mathematics doctorate in hand and a summer to kill. His brother, a neurobiologist, suggested that he learn something about mathematical neural biology. So Lander began to study cell biology, then molecular biology, and finally genetics. Meanwhile, he taught finance at the Harvard Business School. "It's a shaggy dog story," he says, but one that eventually led him to believe that biology's future lay not only in accumulating a mass of genetic data quickly but also in concocting mathematical models to analyze it. By 1990 Lander was director of the Whitehead Center for Genome Research, overseeing labs that deciphered a third of the human genome. He chaired the committee that analyzed the rough genomic data and in 2001 was lead author on the historic paper that offered the complete map of the human genome. Now 45, Lander continues to lead the center's efforts to apply the genome to analyze how cells function and to discover the complex genetic pathways of disease. He advises a number of biotech companies and has become the Carl Sagan of biotech, a charismatic explainer on television programs such as *NOVA*. "Solving the genome was the first step," he says. "Now comes the fun part, when we see how genetics works."

9 Corey Goodman

CEO, Renovis | For 25 years this neurobiologist mapped brain mechanisms such as how neurons behave as they fire off billions of commands that make us move, think, and remember. Using fly brains, Goodman discovered a raft of brain-control genes with equivalents in humans, including several involved with brain development. The research could lead to repairs for injuries to the brain and spinal cord. He is a cofounder of two biotech companies: Exelixis and Renovis. The latter hopes to turn his discoveries into therapies for pain, eating disorders, depression, schizophrenia, and Parkinson's disease. Despite a talent for business, Goodman had always chosen to remain in his lab at the University of California at Berkeley, where he had been director of the Helen Wills Neuroscience Institute since 1999. But Renovis investors recently asked him to become their chief executive. "Initially, I said no. But I think that in the next 10 years, the commercial route will have more of a direct impact on spinal-cord injuries, and maybe on psychiatric disorders, so I decided to take a chance."

10 Sydney Brenner

Distinguished Professor, Salk Institute | In 1962 this South African chemist teamed up with Nobel Prize–winning geneticist Francis Crick at Cambridge University to discover the essence of genetic coding: Every three DNA base pairs (made up of A, C, G, and T combinations) are a code for a single amino acid. Brenner went on to find messenger RNA in cells. Last year, at age 74, he retired as president and director of science at the Molecular Sciences Institute in Berkeley, California. But he continues to pick apart pufferfish in a quest to study gene regulation. "I am taking genes from a pufferfish and inserting them into a mouse to see if they can be read by the mouse," he says. Brenner holds numerous patents, mostly for computational inventions to sequence DNA and other molecules, and remains on the board of Lynx Therapeutics and NeoGene Technologies. He still analyzes pufferfish, now in a lab at the Salk Institute near San Diego.

11

George Rathmann

Chairman, Hyseq | More than a decade ago, a colleague faked a *Time* magazine cover with Rathmann's photo and a headline about his triumphs at the pharmaceutical company Amgen. "It was almost laughable because it was so absurd. We were nothing in the equation of biotech companies, much less American industry," Rathmann remembers. Now Amgen is worth more than $64 billion. Two of its biotech drugs—Epogen, for anemia in kidney-dialysis patients, and Neupogen, used to prevent infection in chemotherapy and bone-marrow transplant patients—earned $3.5 billion last year. Rathmann's contribution to the company's rise came not only from discovering new protein pathways but also from helping to pioneer a business culture for a company that successfully fuses research and industry. Before he went to Amgen, Rathmann worked as a scientist and executive at 3M and at Abbott Laboratories. In 1990 he founded a company called ICOS, which now has nine drugs in human trials for conditions such as sepsis and hypertension. Recently, the 74-year-old became the board chairman of the start-up Hyseq, another new drug company. Is the pie big enough for so many firms? "There are $15 billion to $20 billion of biotech sales today," says Rathmann. "Twenty years ago sales were zip. The potential seems unlimited."

13

Robert Langer

Professor of Chemical and Biomedical Engineering, MIT | Langer has created a blizzard of inventions and discoveries in his lab at MIT, including polymers that deliver macromolecules such as peptides, magnetically controlled implants that release drugs, and 3-D polymer scaffolds on which human tissue can be grown. The 53-year-old has also seen 80 companies develop from his licenses and patents, developed 401 patents, and published 704 articles, not to mention 13 books. His drug-release mechanisms are now the basis of a $20 billion industry and part of his vision for the future. "A

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Mark Levin

CEO and Chairman of the Board, Millennium Pharmaceuticals | In 1979 he owned a doughnut shop in Eden, North Carolina, where he also helped start up and manage a new brewery for Miller Beer. Now éclairs and lagers are less meaningful for Levin. Since 1993 he has been the chief executive officer of Millennium, one of a handful of biotech companies with a market capitalization of more than a billion dollars. Under Levin, Millennium has already launched two drugs, one for heart disease and one for leukemia, and has 10 more in trials to treat conditions such as prostate cancer, asthma, and inflammation. Levin earned a master's degree in biochemical engineering from Washington University in St. Louis. His business-science acumen was developed at Eli Lilly, Genentech, and the Mayfield Fund, where he founded 10 biotech companies. Levin's vision of success for Millennium is to have it lead a revolution in personalized medicine. He foresees a day when "we can go into a doctor's office, and our genome will be available on a chip, and the doctor will be able to treat us for our own genome."

time is coming when the medicines we take will be automated, and tissue engineering will be a part of life," Langer says.

14 Tom Cech

President, Howard Hughes Medical Institute | Cech was only 41 when he and Yale's Sidney Altman won the 1989 Nobel Prize in chemistry by proving that RNA could be a biocatalyst. That research led to the discovery of tiny ribozymes that can be used as drugs. Cech also discovered the first protein component of telomeres, as well as the catalytic subunit of the telomere-replicating enzyme, telomerase. He holds 12 patents and helped start Ribozyme Pharmaceuticals. And now, as president of the $12 billion Hughes Medical Institute, he is bucking a trend, trying to lure scientists from the biotech business back into research. Before Cech, the institute focused on funding individual scientists' research at universities. Under his leadership, the institute is building a $500 million 281-acre campus in northern Virginia, where physicists, engineers, computer scientists, and biologists can do pure research in an environment that mimics a biotech company. Cech says, "We want to apply principles from biotech to academic research, to break down the barriers in traditional academia so that chemists, biologists, and engineers can work together, with an infrastructure of assembly lines, shops, and labs."

15 David Goeddel

CEO, Tularik | In 1978 Genentech chief Robert Swanson lured this 26-year-old Stanford University postdoc to the biotech company as its first full-time staff scientist. "I was very green, which shows how much trouble they had hiring more experienced people," Goeddel says. "We wanted to make a new drug, and we did it by the next summer." The idea of the drug was old—insulin—but Goeddel developed a way to manufacture it synthetically. He went on to pioneer gene cloning and gene expression techniques for proteins involved in human growth hormone, interferon-alpha, and others that became the basis of Genentech's early pharmaceuticals. In 1991 he cofounded Tularik, a drug-discovery and development company. It now has three anticancer drugs in clinical trials.

16 David Baker

Associate Professor, University of Washington; Assistant Investigator, Howard Hughes Medical Institute | A great conundrum facing biology is how proteins fold—that is, form themselves into shapes like balls of spaghetti—which allows them to attach themselves to other molecules, including

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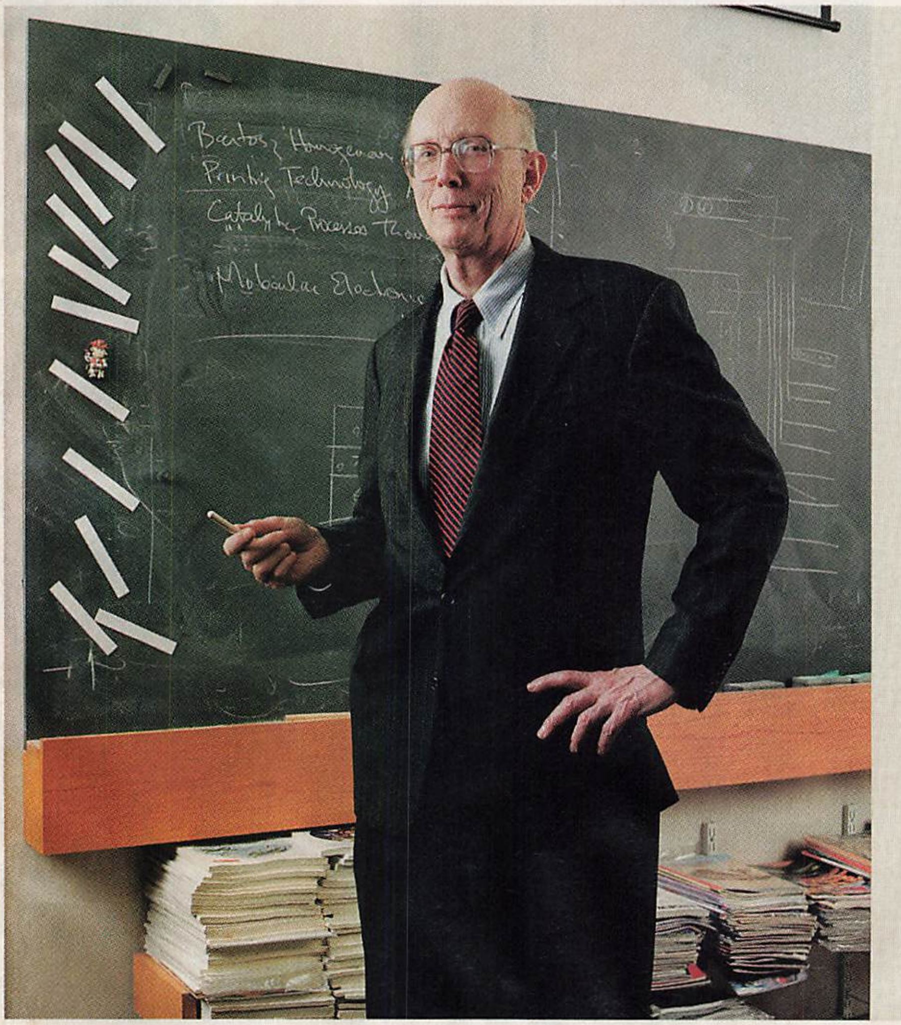


17 George Whitesides

Professor of Chemistry, Harvard University | Small is hot. Nano-enthusiasts talk about building cell-size cancer-killing submarines and creating tiny self-assembling robots that snatch raw ingredients from the environment to self-replicate. Skeptics say that so far it's only talk, and they warn of self-replicating nano-gizmos that could run amok and ravage the planet. Calmly presiding in the middle of the controversy is a 63-year-old National Medal of Science winner and Harvard chemist. One of the first scientists to put the "tech" into "biotech," Whitesides has pushed the boundaries between chemistry and just about every other science. While still in his thirties, he helped pioneer the bioengineering of molecules present in mammalian cells, which laid the foundation for modern biomolecular medicine. Today Whitesides tinkers with neural networks, drugs that interact with multiple proteins, and self-assembling molecules that mimic cell components. "We are about to challenge some basic assumptions about who we are," he says. "What is a machine? What is life?"

18 Gerald Rubin

Professor of Genetics and Development, University of California at Berkeley; Vice President, Howard Hughes Medical Institute | Nature tends to be efficient and therefore repeats basic genetic systems in almost all organisms. Flies are no different, which means flies and humans share an extraordinary number of genes. That simple fact, and lots of work understanding the genetics of the common fruit fly, *Drosophila*, has made quite a success of this 52-year-old professor at the University of California at Berkeley. *Drosophila* is a crucial stand-in for experiments and discoveries applicable to human genetics, making the flies an underpinning of biotech research. "Most of the ways that cells talk to each other are fairly ancient," says Rubin. These days he divides his time between studying systemic gene functions and gene regulation in *Drosophila* and helping Tom Cech develop the new Janelia Farm research campus for the Howard Hughes Medical Institute.

drugs. When they do, they can turn something on or off. Geneticists can identify these shapes only through a costly process called X-ray crystallography. First, proteins must be made into crystals, then X-rayed and modeled on a computer. Baker is short-circuiting the process. In 1997 he created a sensation with his Rosetta algorithm, a computer program that predicts how proteins will fold by using just the sequence of amino acids provided by DNA. So far the program is only 40 percent accurate, but it is far easier than anything else available. This year Baker licensed Rosetta to Structural Genomix, a protein-identification and drug-discovery company in San Diego. "We are about two or three years away from making this useful," he says, "though I've learned that predicting the rate of progress is even harder than predicting proteins."

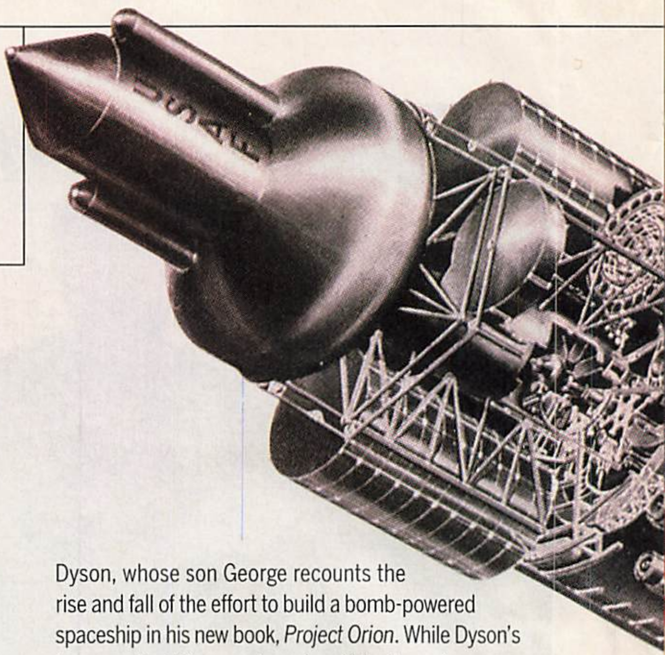
19 Charles Cantor

Chief Scientific Officer, Sequenom | This chemist and inventor is up before dawn every morning, running six miles no matter where he is, which could be anywhere as he relentlessly promotes Sequenom, the drug company he cofounded in 1994. On leave as director of the Center for Advanced Biotechnology at Boston University, Cantor, 59, is a pioneer of "pharmacogenomics," the creation of drugs individually designed for one person's genome. Cantor invented techniques that separate large DNA molecules and detect tiny quantities of DNA and protein. He recently coinvented a fast assembly-line process to discover and analyze single nucleotide polymorphisms—pieces of genes responsible for specific genetic proclivities, including such conditions as cardiopulmonary diseases, depression, and anxiety. "I like to solve problems," he says. "I get bored very quickly. I fall asleep. To stay awake, I just invent my own problems and try to solve them."

20 Arthur Levinson

Chairman and CEO, Genentech | If there is an ancestral birthplace of the biotech industry, it's Genentech. Founded in 1976 by legends Robert Swanson and Herbert Boyer, it began as an experiment to see whether Boyer's new recombinant DNA technology could be turned into a business. In 1980 Boyer recruited Levinson, a young microbiologist from the University of California at San Francisco. Unlike many biotech luminaries who cut their teeth at Genentech and left, Levinson stayed, moving up from senior scientist to chief executive officer in 15 years. He took over the company in 1995, when biotech stocks were plummeting as drug after drug fizzled. Levinson ratcheted up the research budget and raised money using innovative alliances with other companies. He now presides over a business with 10 drugs on the market and a $27 billion market cap. ☒

REviews



PHOTOGRAPH COURTESY OF HENRY HOLT AND COMPANY.

The Golly Gee-Whiz Atomic Spaceship

The forgotten quest to build a rocket propelled by thousands of hydrogen bombs **By Tim Folger**

Project Orion:
The True Story of the Atomic Spaceship
By George Dyson
Henry Holt and Company, $26

THE RACE INTO SPACE WAS ON, AND THE UNITED STATES WAS LOSING. THE SOVIET UNION launched the 184-pound satellite *Sputnik* in October 1957 and just one month later sent a dog into orbit on *Sputnik II*. The United States followed in January 1958 with the 31-pound satellite *Explorer I*. Even as the nascent U.S. space program focused on pint-size payloads, however, a research team at an obscure division of the General Dynamics Corporation was secretly drawing up plans for a monstrous 4,000-*ton* spaceship that would be powered by the sequential explosions of thousands of hydrogen bombs and would ferry hundreds of astronauts at a time across the solar system. Indeed, the physicists who worked on the project were so confident their design would be a success that they adopted an ambitious motto: "Saturn by 1970."

The gargantuan Orion spaceship never made it past the blueprint stage, much less to Saturn. Nonetheless, until the project was shut down in 1965, some of the nation's best scientists chased what now seems a patently ridiculous dream. Among them was physicist Freeman Dyson, whose son George recounts the rise and fall of the effort to build a bomb-powered spaceship in his new book, *Project Orion*. While Dyson's language is at times awkward and his chronology confusing, the sheer outlandishness of the forgotten space endeavor is nothing less than fascinating.

Nearly all the Orion scientists Dyson interviewed fondly recall the excitement that surrounded the project. The late 1950s and early 1960s was an era when the United States and the Soviet Union, unrestricted by any treaty, exploded huge hydrogen bombs in the atmosphere. Both nations were building nuclear-powered ships and submarines. Why not an enormous bomb-driven spaceship? With only conventional rockets humans might travel as far as Mars but no farther. For Dyson's father and his fellow physicists, the lure of building a spacecraft that could travel to the moons of Saturn and back within four years was irresistible.

The favored design called for a heavily shielded, bullet-shaped spacecraft as tall as a 10-story building, mounted on four 20-foot-long shock-absorbing columns. Attached to the base of the shock absorbers was a thousand-ton disk-shaped "pusher plate." Hydrogen bombs were to be ejected from the ship—at a rate of about one every

MOVIES

Kilimanjaro:
To the Roof of Africa
IMAX Movie
Directed by
David Breashears

FOR DAYS THE INTREPID CLIMBER HAS STRUGGLED UP THE SLOPES OF MOUNT KILIMANJARO. HIS journey, begun in the moss-draped rain forests at the foot of the mountain, has led him upward through heaths, moorlands, and alpine deserts into the embrace of clouds. The peak, capped in snow and glacial ice, lies above and still ahead. Our protagonist yearns to rest. He yearns to reach the top. He yearns for soap. "I'm kind of smelly," he says. "And I think also the others haven't bathed."

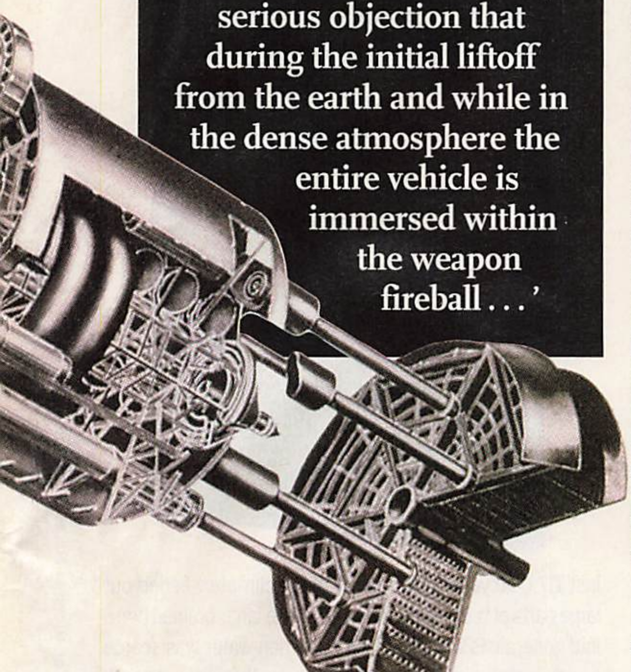
That's Hansi Mmari, age 13, one of several amateur adventurers who enliven *Kilimanjaro: To the Roof of Africa*, the latest IMAX feature from filmmaker David Breashears. Standing 19,340 feet tall, Kilimanjaro is only two-thirds as tall as Everest. But what it lacks in stature, Kilimanjaro more than makes up for with its rich natural history. It rose 360,000 years ago from the Great Rift Valley, a vast tectonic divide that runs through East Africa, and grew to become the largest volcano (now a dormant one) on any continent.

Kilimanjaro's slopes span the climatic range, from tropical to arctic; climbing from base to peak "is like walking from the equator to the North Pole in only a week," as one trekker in the film says. Average temperature and rainfall drop steadily as the elevation rises: Lush forests give way to exposed heaths bright with wild irises and gladioli, which turn to boggy moors. These moorlands at the upper reaches of the mountain are a battle zone for plants; lobelias and groundsels have developed ingenious tactics to preserve moisture in an environment where the soil freezes at night and the sun's rays scorch them by day. Above 15,000 feet there is virtually no life at all, only statuesque glaciers that never melt but simply evaporate directly into thin air under the tropical sun. And there are signs of lowland visitors: leopards, eland, elephants whose bones suggest they wandered up for the view and stayed for eternity.

These natural wonders are revealed gracefully through a human adventure, the story of five amateur mountaineers who, like 11,000 other people a year, attempt to reach Kilimanjaro's summit. The film isn't a true documentary; the trek

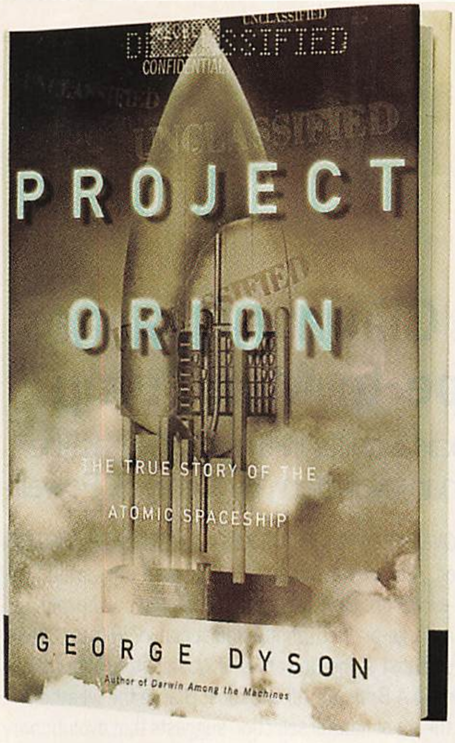
From *Project Orion,* p. 79:

'. . . the whole thing looks feasible except for the very serious objection that during the initial liftoff from the earth and while in the dense atmosphere the entire vehicle is immersed within the weapon fireball . . .'



The basic Orion design: Helix-shaped containers house hydrogen bombs, to be ejected through a hole in its "pusher plate," at bottom.

PHOTOGRAPH BY JENS MORTENSEN.


DECLASSIFIED
UNCLASSIFIED
CONFIDENTIAL
PROJECT ORION
THE TRUE STORY OF THE ATOMIC SPACESHIP
GEORGE DYSON
Author of Darwin Among the Machines

second—through a hole in the center of the pusher plate. The bombs would detonate about 100 yards from the ship. The blasts from successive explosions would smash against the plate and accelerate the ship.

A three-foot-tall prototype powered by conventional explosives was flown to a height of 185 feet, demonstrating, to the project's supporters at least, the plausibility of the idea. But before the Orion team could build a prototype with nuclear bombs, the atmospheric test ban treaty of 1963 killed the project.

Much about Orion remains classified even today. The research led to advances in the design of compact nuclear weapons and in funneling the energy of their explosions, secrets the military jealously guards to this day. Some physicists still won't dismiss the idea of a bomb-powered ship, arguing that it could be stationed in orbit, eliminating the dangers of atmospheric contamination that plagued the original Orion. Such a ship would open up the solar system, and perhaps the stars, to human exploration. It might even be used to destroy an asteroid on a collision course with our planet. Four decades after working on Orion, physicist Bud Pyatt insists that the project was simply ahead of its time. "It would have worked," he says now. "Even in my dotage, I'm a true believer."

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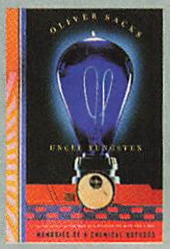
team was handpicked by Breashears to represent a diversity of perspectives. There's the Tanzanian boy, Hansi, and a 12-year-old girl from Massachusetts who has longed to climb Kilimanjaro since, oh, forever. Also in tow are a 55-year-old British geophysicist, a 64-year-old writer of mountaineering books, and a 23-year-old Danish model and painter whose "extroverted nature inspired her comrades," or so say the filmmakers. Their guide, Jacob Kyungai, who grew up in a village at the base of Kilimanjaro and has climbed the mountain more than 250 times, provides the film's sonorous narration.

Their story does seem, at times, overly contrived. The trekkers are revealed largely through voice-overs, and much of that material is obviously scripted. Surely not even the most articulate geophysicist tosses off a remark like, "Scorching rivers of lava poured down these slopes, and eruptions lit up the night sky." Nor is it likely that a Danish model with otherwise fractured English would say, in casual conversation, "In such thin, dry air, this ice is completely exposed to the intense rays of the tropical sun. That, along with the sculpting force of the wind, creates phenomenal shapes." And the musical score could have done with a few less trumpets. Why does every new IMAX film score sound like the theme to *Bonanza*?

On the other hand, the film is a splendid mix of cinema vérité and big-screen grandeur. The trekkers are given enough impromptu lines (on the subject of body odor, for instance) to reveal some real personality. And the hard work of hiking uphill is all theirs, not some camera trick. Anyway, the point of an IMAX film is to be larger than life. When the view is as stunning as what Kilimanjaro offers, mere plot devices pale in comparison. *—Alan Burdick*

BEST-SELLERS

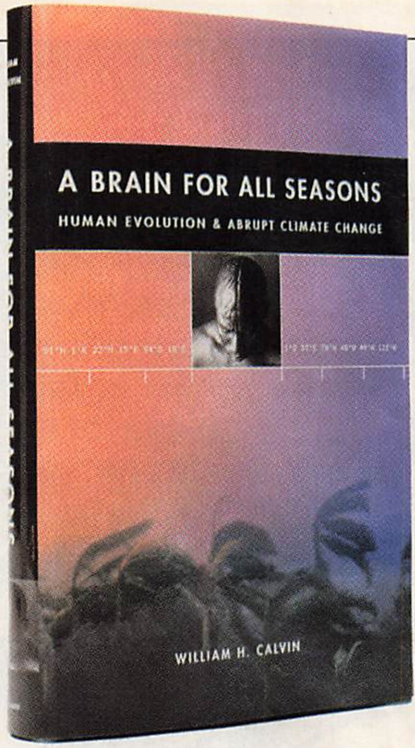
1. **THE UNIVERSE IN A NUTSHELL**
   By Stephen Hawking, Bantam
2. **THE FUTURE OF LIFE**
   By E. O. Wilson, Knopf
3. **THE STRUCTURE OF EVOLUTIONARY THEORY**
   By Stephen Jay Gould, Harvard University Press
4. **HOW TO BUILD A TIME MACHINE**
   By Paul Davies, Viking
5. **UNCLE TUNGSTEN: MEMORIES OF A CHEMICAL BOYHOOD**
   By Oliver Sacks, Knopf



Sacks recalls his childhood in wartime England and his early love of chemistry's mysteries.

6. **THE SKEPTICAL ENVIRONMENTALIST: MEASURING THE REAL STATE OF THE WORLD**
   By Bjørn Lomborg, Cambridge University Press
7. **SYNAPTIC SELF: HOW OUR BRAINS BECOME WHO WE ARE**
   By Joseph LeDoux, Viking
8. **GENES, GIRLS AND GAMOW: AFTER THE DOUBLE HELIX**
   By James D. Watson, Knopf
9. **SIX EASY PIECES AND SIX NOT-SO-EASY PIECES**
   By Richard Feynman, Perseus
10. **THE BIRDS OF HEAVEN: TRAVELS WITH CRANES**
    By Peter Matthiessen, North Point Press

Source: Barnes & Noble Booksellers



Can Whiplash Climate Changes Explain the Ape-to-Man Jump?

New evidence points to radical shifts in the weather as the surprising catalyst for human evolution **By Corey S. Powell**

WE FREQUENTLY GET LETTERS AT *DISCOVER* FROM SKEPTICS WHO QUESTION THE NOTION that humans have descended from apes. And we have to admit that even dedicated Darwinians are baffled by a conundrum of evolution: How did humans diverge so sharply and rapidly from other primates and emerge as large-brained, chatty, and sociable? William Calvin, a behavioral scientist at the University of Washington, offers a surprising answer in *A Brain for All Seasons:* Blame the weather.

A Brain for All Seasons:
Human Evolution & Abrupt Climate Change
By William H. Calvin
University of Chicago Press, $25

The basic theory of natural selection suggests that evolutionary change grows out of the random variations found in any population. Depending on local conditions, some organisms will be more successful than others: They might have slightly thinner fur, smaller teeth, or some other traits that prove beneficial. The average form and features of the next generation will be slightly different because of unequal survival rates, and the cycle repeats. Scientists traditionally pictured this process happening in a leisurely manner, nudged along in part by gradual environmental shifts. Beginning in the mid-1980s, however, a number of researchers recognized that Earth's climate sometimes changes drastically in just a few years. Those crazy times, Calvin argues, are the key to understanding human origins.

During whiplash climate changes, temperatures plunge and horrible droughts set in. Calvin envisions groups of hominids migrating to shriveled lakes and watering holes, drawn by the concentration of game animals. In such relatively compact social settings, altruism might have been a useful strategy for those protohumans able to recall which individuals had shared fairly and which had not. The herds of prey loitering around the watering hole might also have encouraged cooperative, semiskilled hunting by using what Calvin describes as Killer Frisbees—the enigmatic triangular stones with sharpened edges found at many hominid fossil sites. Ecological crises occurred repeatedly over the past two and a half million years, especially during the ice ages of the last 117,000 years. Each swing of the climate weeded out large parts of the population, favoring the large-brained hominid generalists who could survive when water was scarce and then thrive in the lush savanna once the rains returned.

All of this is necessarily speculative. Many behaviors do not leave any traces, and fossils are much more effective at recording what happened rather than why. Calvin addresses these uncertainties and invites readers to examine his evidence by structuring the book as a travelogue. You join him as he watches the animals around a Masai watering hole, observes sea ice floating off Greenland, and accompanies a fossil excavation in the Sterkfontein Grotto of South Africa. The flood of information is persuasive, if a little overwhelming.

Why don't we see great leaps in primate evolution now? One part of the answer is that major changes generally take a long time for slow-reproducing creatures like ourselves. But radical climate changes could quickly do a number on us, Calvin warns: "The result would be a population crash that would take much of civilization with it, all within a decade."

PHOTOGRAPHS: TOP, JENS MORTENSEN; BOTTOM, COURTESY OF MICRO LOGIC CORPORATION.

From *A Brain for All Seasons*, p. 8:

> **We could go back to ice-age temperatures within a decade—and judging from recent discoveries, an abrupt cooling could be triggered by our current global-warming trend. Europe's climate could become more like Siberia's.**

TOYS

THE SIMPLE GYROSCOPIC MOTION OF TOY TOPS HAS BEEN A SOURCE OF HYPNOTIC APPEAL since time immemorial. But the latest tops are a far cry from the small clay cylinders that mesmerized children in ancient Rome and Greece. Take the combat-ready Beyblade (www.hasbro.com), which inspired a Japanese cartoon featuring gladiator-style battles with spin tops. Powered by a plastic rip-cord launcher, the saucer-shaped Beyblade measures about an inch and a half across. It comes equipped with mix-and-match components, including attack rings with various spikes and flanges designed to knock other tops out of a plastic arena that comes in three sizes, ranging in width from 16 to 21¾ inches. Interchangeable bases with different-shaped points affect the spin motion; a duller point, for instance, increases the friction so that the top skitters in a helter-skelter fashion.

Old-fashioned string-wound peg tops tricked out with independently rotating tips are the rage with the skateboard-and-dirt-bike crowd. Duncan Toys representative Steve Brown, a competitive spinner, can release a top, snare its tip back on the string, twirl the top over his head, slide it in a spiral down his arm, and then con-

BOOKS

A FREAKISH ACCIDENT TURNED PHINEAS GAGE, a railroad construction foreman, into an unwitting pioneer of modern brain science. On September 13, 1848, in Cavendish, Vermont, Gage was preparing black gunpowder for blasting when his tamping rod—a 3-foot-7-inch, 13½-pound iron bar—unexpectedly slipped from his hands and struck a spark. The resulting explosion shot the iron like a missile straight through his head. Remarkably, Gage never lost consciousness and survived another 11 years. But he underwent a startling personality transformation, turning strangely profane and unpredictable. His case astonished doctors and offered some of the first insights into the relationship between personality and the workings of the brain's frontal cortex.

Phineas Gage: A Gruesome but True Story About Brain Science

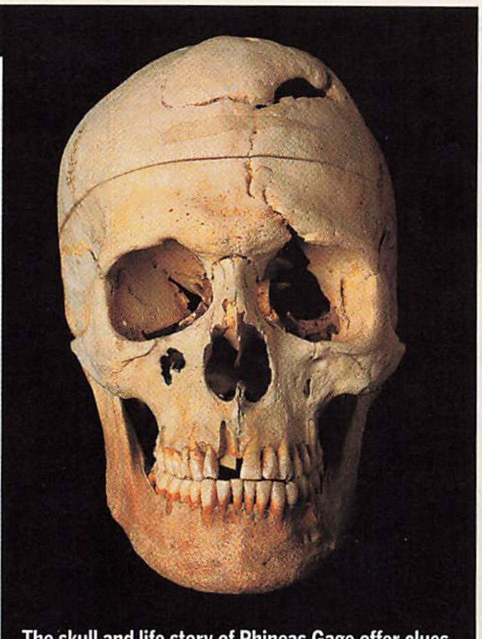
By John Fleischman

Houghton Mifflin Company, $16

In *Phineas Gage: A Gruesome but True Story About Brain Science,* an illustrated volume intended primarily for young readers (ages 10 and up), author John Fleischman weaves fascinating science into a stylish narrative that is likely to pique the curiosity of adults too. Fleischman provides a fascinating glimpse of 19th-century medical practices. But he also explores contemporary research related to the Gage case.

Antonio and Hanna Damasio, husband-and-wife brain researchers, study changes in the brains of patients who, as the result of drastic surgeries to remove tumors deep in the cortex, sustain neurological damage that makes them emotionally unstable. In 1994 the Damasios constructed a postmortem brain scan of Gage to see if they could precisely map the damage to his cortex. After taking measurements of his skull, which resides at Harvard Medical School, they devised a computer model of his brain and generated 16 possible paths that the tamping iron could have taken. Their final model suggests that the rod caused extensive damage in the ventromedial region, which regulates moods and many cognitive functions, but bypassed the area of the frontal cortex that controls speech, as well as several other regions that integrate sensory input and muscle activity.

Exactly 150 years after the tamping rod bored a hole in Gage's head, neurologists from around the world gathered near the site of the accident to discuss frontal cortex injuries. At the end of his life, Gage was shunned by his neighbors. But at the conclusion of the conference, Cavendish town fathers unveiled a plaque commemorating his contribution to medical science. Gage's battered skull was driven up from Harvard just for the occasion, cradled in the back seat of a limousine. —*Deborah Hudson*



The skull and life story of Phineas Gage offer clues to how a frontal lobe injury can affect personality.

PHOTOGRAPHS: TOP, COURTESY OF HOUGHTON MIFFLIN; BOTTOM, COURTESY OF DUNCAN TOYS.

WE ALSO LIKE

FLESH AND MACHINES: HOW ROBOTS WILL CHANGE US

Rodney A. Brooks

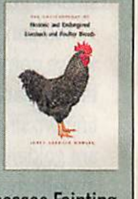
Pantheon, $26

The director of MIT's Artificial Intelligence Laboratory envisions a time when humans and robots will become so physically interdependent that the distinctions between them will be blurred. People will function with the aid of implanted microchips, for example, and androids possessing heightened intelligence and sensing capabilities will be generally thought of as living beings.

THE ENCYCLOPEDIA OF HISTORIC AND ENDANGERED LIVESTOCK AND POULTRY BREEDS

Janet Vorwald Dohner

Yale University Press, $75



The streamlining of the agriculture industry has decimated many once-flourishing breeds, such as the Barbados Blackbelly sheep and the Tennessee Fainting goat, which Dohner catalogs in this lavishly illustrated volume.

LOST LANGUAGES: THE ENIGMA OF THE WORLD'S UNDECIPHERED SCRIPTS

Andrew Robinson

McGraw-Hill, $34.95

Learn how anthropologists and linguists cracked the codes to three ancient scripts—Egyptian hieroglyphs, Greek Linear B, and Mayan glyphs—and why the writings left behind by nine other ancient civilizations, including the Etruscan alphabet and Greek Linear A, may remain a mystery forever.

IT MUST BE BEAUTIFUL: GREAT EQUATIONS OF MODERN SCIENCE

Edited by Graham Farmelo

Granta Books, $25

A dozen prominent scientists and journalists, including the Nobel Prize–winning physicist Steven Weinberg, provide illuminating essays on the origins of such landmarks of scientific thinking as Einstein's famous $E=mc^2$ and the Drake Equation, which predicts how much intelligent life the universe holds.

—*Maia Weinstock*

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tinue spinning it in his hand. The key is a ball-bearing mechanism in the tip that reduces friction. Aspiring stunt spinners can experiment with the Spintastics Blizzard (www.spintastics.com) or the Duncan Bearing King (www.yo-yo.com), shown at left.

For spinners in quest of a top that just keeps on going, Jim Lewis of Micro Logic Corporation developed the Quark Top (www.miclog.com). His models have a light plastic core and a heavy rim made of brass (shown at far left), heavier tungsten, or gold. Added weight in the rim increases the top's angular momentum, allowing it to spin longer. To perfect the top's balance, the Quark Top comes with a laser pointer that bounces a laser beam off the spinning rim: If the reflected laser beam shows up as a dot on the ceiling, the top is perfectly balanced; if it appears as a small circle, the top is wobbling, and the weight distribution must be adjusted by adding small washers to slots in the top's underside. Perfectly calibrated, the brass top will spin for 15 minutes, the tungsten for 22 minutes. Lewis isn't sure how long the gold top will spin: He's waiting for someone to order one, at a price of $2,495, so he can find out. —*Fenella Saunders*

The Tops

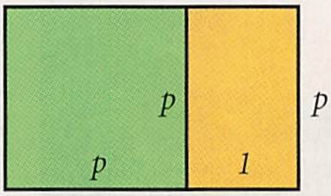
Beyblade, $6.99;
Blizzard, $15; Bearing King, $15.99; Brass Quark, $49.95; Tungsten Quark, $149.95

IDEAL PROPORTIONS

The math behind music, art, and games

GOLDEN RULES

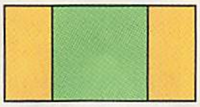
A golden rectangle is a rectangle whose sides are proportional in what is known as the golden ratio. The pleasing, precise proportions of the golden rectangle have been present in the works of architects, artists, and sculptors throughout the ages. Even photographs and index cards often come in these same golden proportions. As shown at right, in a golden rectangle, when you lop off a square (the green shaded area), the remaining piece is another, smaller golden rectangle.



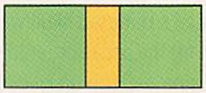
You can derive the golden ratio from the golden rectangle above, which comprises a green square of side *p* and a smaller yellow rectangle that has a short side one unit in length and a long side *p*. By definition, since both the overall rectangle and the small yellow rectangle are golden rectangles, the ratio of the longer side to the shorter side of both rectangles must be equal. Therefore $p/1 = (p + 1)/p$, which means $p^2 = p + 1$. With a bit of algebra, we can see that $p = (1 + \sqrt{5})/2$, or 1.61803 . . . This is the golden ratio.

Here are some other interesting rectangles. In each case the green rectangles are squares, and the yellow rectangles have the same proportions as the whole rectangle. Can you figure out the numerical value of each rectangle's proportions? You might need to pull out your old algebra book for problems 4 and 5.

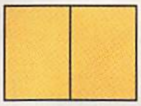
[Easy] 1.



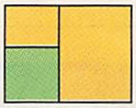
[Easy] 2.



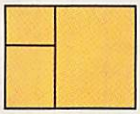
[Medium] 3.



[Medium] 4.



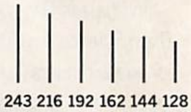
[Hard] 5.



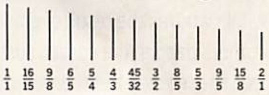
TUNING UP

Pythagoras was one of the first to discover that harmonious musical intervals correspond to whole-number ratios. Try it: Pluck a guitar string. Press the string to the fret board at the halfway point and pluck again. This note is an octave higher than the first and corresponds to the ratio 2:1—the first two notes of "Over the Rainbow." The interval between one string and another two-thirds as long, 3:2, is a perfect fifth—think of the *Star Wars* theme. A major third—the third and fourth notes in Beethoven's Fifth Symphony—corresponds to the ratio 5:4.

[Easy] 1. You can determine the interval between two strings by dividing the longer length by the shorter length. Intervals are equivalent if the fractions are the same, or if one fraction can be made to equal another by repeatedly multiplying it by 2 (which changes the pitch by an octave), by inverting it (which reverses the order of pitches), or by doing both operations. The intervals 3/2 and 4/3 are equivalent: A string 3 units in length and another 2 units in length, played in reverse order (2/3), are equivalent. Double the shorter string, and the resulting interval (4/3) is the same, with one note an octave lower. How many distinct intervals do these six strings comprise? For example, the interval between the two left strings is 243/216, or 9/8.



[Medium] 2. Scales in what is called just intonation are tuned so that every note is an exact whole-number ratio when compared with the starting note. Below are the strings of one 12-note scale in just intonation. Pitches are expressed as fractions; the string labeled 9/5 is five-ninths the length of the longest one. Differences in length between adjacent strings, called half steps, vary. How many distinct half steps are in this scale?

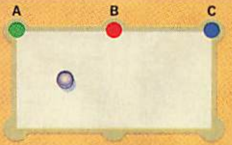

$\frac{1}{1}$ $\frac{16}{15}$ $\frac{9}{8}$ $\frac{6}{5}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{45}{32}$ $\frac{3}{2}$ $\frac{8}{5}$ $\frac{5}{3}$ $\frac{9}{5}$ $\frac{15}{8}$ $\frac{2}{1}$

[Hard] 3. The equal-temperament tuning system adjusts the intervals in the 12-tone scale so that all half steps are equal. A half step is now the 12th root of 2—the number that equals 2 when multiplied by itself 12 times (written as $2^{1/12} = 1.05946\ldots$). The perfect fifth is almost exactly 3/2 ($2^{7/12} = 1.49831\ldots$). Unfortunately, the major third ($2^{4/12} = 1.25992\ldots$) is not as close to 5/4 as one would like.

What if an octave comprised more than 12 notes? What is the smallest number of notes in an equal-tempered octave that would include a pitch that (a) better approximates the ratio of a major third in just intonation (5/4), (b) better approximates the ratio of a perfect fifth in just intonation (3/2), and (c) approximates both the major third and the perfect fifth better than the 12-tone scale does?

WORKING THE ANGLES

Every game has its own shape—baseball is played on a diamond, soccer on a rectangle, and marbles in a circle. Pool is played on a table made up of two squares, and to play the game well requires a knowledge of angles.



Place a ball at the center of one of the two squares. Where should you shoot the ball so that it bounces off each of the four sides of the table exactly once before landing in pocket A? How about pocket B or C? Which of these three problems has two different solutions? Of the two alternate solutions, which is shorter? Assume that the ball bounces off a cushion at the same angle it approached it, like light bouncing off a mirror. A ball can land in a pocket only if it is aimed exactly at the center of the pocket.

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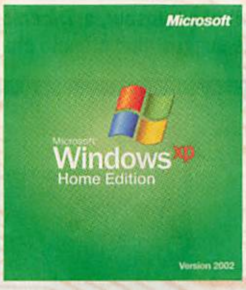

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Disqualification and the selection of an alternate winner will result from any of the following: (1) failure of a potential winner to respond to U.S. Mail notification within fourteen (14) days from the date of mailing; (2) failure of a potential winner to execute and return an Affidavit of Eligibility/Liability/Publicity Release within fourteen (14) days from the date of notification; (3) the return of any notification or prize as undeliverable; (4) potential winner's failure to claim a prize within fourteen (14) days after being sent; or (5) any other non-compliance with Rules. All taxes are solely the winner's responsibility. For list of winners (after July 5, 2002), and/or Rules (before June 17, 2002), send a postage prepaid business size (#10) envelope, to: DISCOVER MAGAZINE'S DIGITAL REVOLUTION SWEEPSTAKES, Attn: Meredith Morgans, 114 Fifth Avenue, 16th Floor, New York, NY 10011. 7. 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re sources

The following books, journals, and Web sites provide additional information about topics featured in *Discover* this month.

14 R&D

"Chaotic Warnings From the Last Ice Age." Ganopolski, Andrey, and Stefan Rahmstorf. "Abrupt Glacial Climate Changes Due to Stochastic Resonance." *Physical Review Letters* 88 (January 21, 2002): 38501. See http://prl.aps.org. Rahmstorf's Web site offers more information: www.pik-potsdam.de/~stefan.

"Evolution's Big Bite." Purnell, Mark A. "Feeding in Extinct Jawless Heterostracan Fishes and Testing Scenarios of Early Vertebrate Evolution." *Proceedings of the Royal Society of London, Series B,* 269 (January 7, 2002): 83–88.

"Data Points." Braksiek, Robert J., and David J. Roberts. "Amusement Park Injuries and Deaths." *Annals of Emergency Medicine* 39 (January 2002): 65–72.

"Cold Fusion Redux?" Taleyarkhan, R. P., et al. "Evidence for Nuclear Emissions During Acoustic Cavitation." *Science* 295 (March 8, 2002): 1868–1873. Read Shapira and Saltmarsh's comments at www.ornl.gov/slsite/SLan5av2.pdf. Read the Taleyarkhan team's rebuttal at www.eurekalert.org/pub_releases/science/2002-03/TaleyarkhanResponse.pdf.

"Ancient Lotus Returns to Life." Shen-Miller, J. "Long-Living Lotus: Germination and Soil gamma-Irradiation of Centuries-Old Fruits, and Cultivation, Growth, and Phenotypic Abnormalities of Offspring." *American Journal of Botany* 89 (February 2002): 236–247.

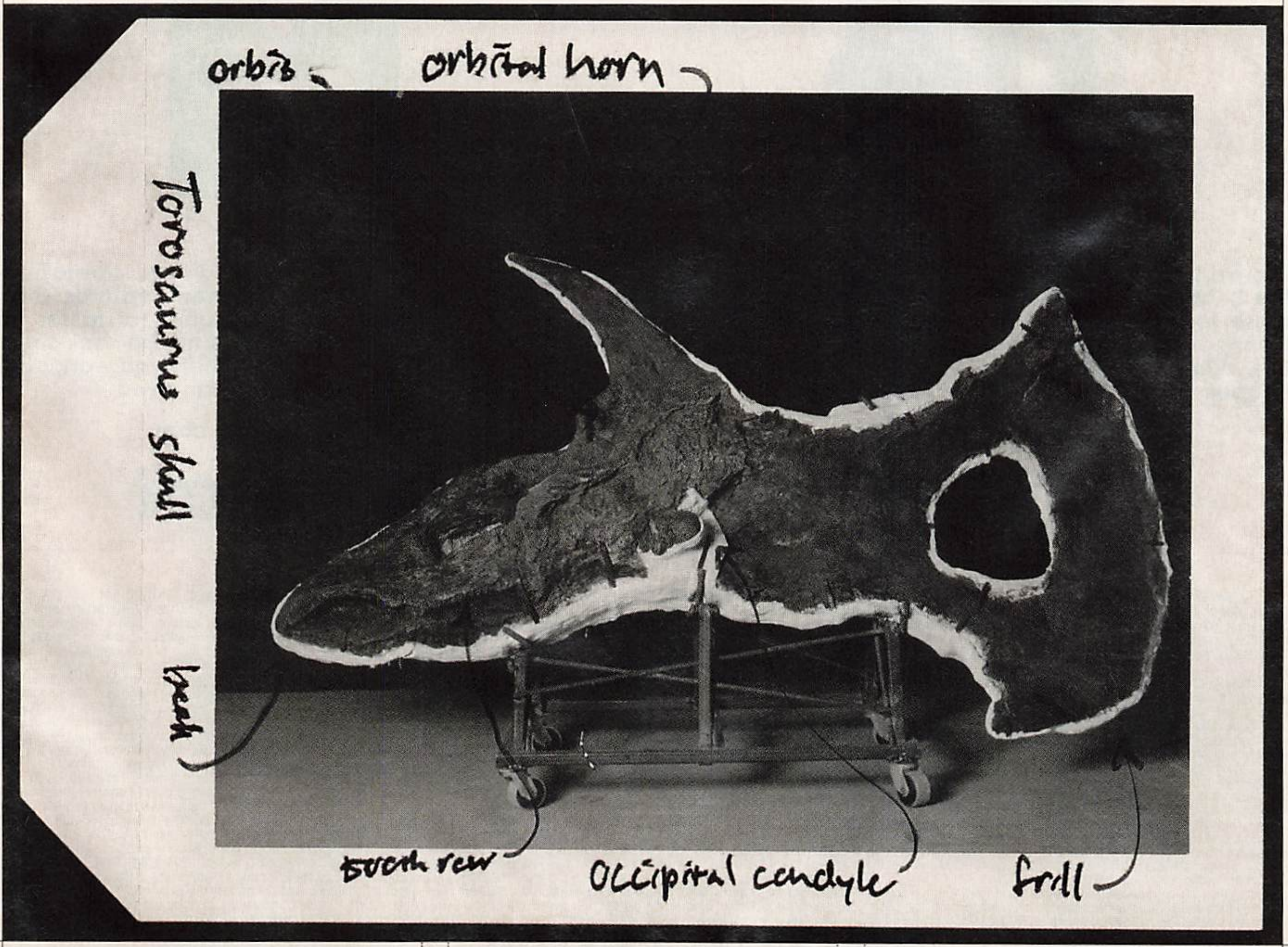
"Liquid Lights the Way." Kerbage, C., et al. "Electrically Driven Motion of Micro-fluids in Air-silica Microstructure Fiber: Application to a Tunable Filter/Attenuator." *2002 Optical Fiber Communication Conference Technical Digest.* See www.osa.org.

"Landmarks." The history of the Horn and Hardart Automat appears at www.smithsonianmag.si.edu/smithsonian/issues01/aug01/object_aug01.html. For the EPA's order banning DDT, see www.epa.gov/history/topics/ddt/01.htm. Barbara McClintock's discoveries are described at www.nationalacademies.org/history/members/mcclintock.html.

"Tributes." More about César Milstein's work can be found at the Nobel e-museum: www.nobel.se/medicine/laureates/1984.

"An Artificial Eye on Bioterror." The group's Web page is www.health.pitt.edu/RODS. Moore's Web page is www-2.cs.cmu.edu/~awm/hp.html.

Below: The skull of a torosaur, a *Triceratops*-like creature, was discovered last summer at the Hell Creek Formation in Montana. Fossils found at the site suggest that climate changes during the Cretaceous Period may have led to the dinosaurs' demise. See page 36.



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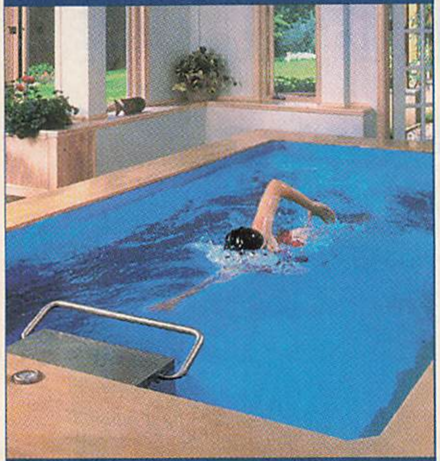

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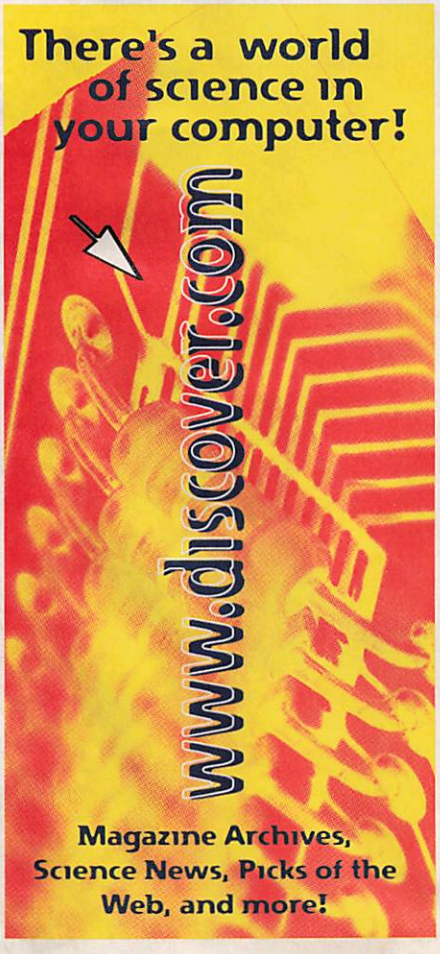
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resources

"SIM Surgery." See a computer rendition of one of the new surgical trainer bodies: www.cardiff.ac.uk/news/releases/0203/04/img1.jpg.

"Monkey Users Are Losers." Morgan, D., et al. "Social Dominance in Monkeys: Dopamine D2 Receptors and Cocaine Self-administration." *Nature Neuroscience* 5 (February 1, 2002): 169–174.

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"Imagining Saturn Without Its Rings." Search NASA's gallery for images of Saturn: http://photojournal.jpl.nasa.gov.

"Set the Remote to 'DNA.'" Hamad-Schifferli, K., et al. "Remote Electronic Control of DNA Hybridization Through Inductive Coupling to an Attached Metal Nanocrystal Antenna." *Nature* 415 (January 10, 2002): 152–155.

"A Wrinkle in Space-Time." Lieu, Richard. "The Effect of Planck-Scale Spacetime Fluctuations on Lorentz Invariance at Extreme Speeds." *The Astrophysical Journal Letters* 568 (April 1, 2002): L67.

"Noise to the Ears." Ayotte, Julie, et al. "Congenital Amusia—A Group Study of Adults Afflicted With a Music-specific Disorder." *Brain* 125 (February 2002): 238–251.

"You Look Good Enough to Eat." Rodd, F. Helen, et al. "A Possible Non-sexual Origin of Mate Preference: Are Male Guppies Mimicking Fruit?" *Proceedings of the Royal Society of London, Series B* 269 (March 7, 2002): 475–481.

"*Discover* Dialogue." Find more about Vera Rubin at www.physics.ucla.edu/~cwp/Phase2/Rubin,_Vera_Cooper@931234567.html. The life of Cecilia Payne-Gaposchkin is described at www.astr.ua.edu/4000WS/GAPOSCHKIN.html.

"Follow-Up: The Walking Wheelbarrow." Neuhaus, Peter, and H. Kazerooni. "Industrial-Strength Human-Assisted Walking Robots." *IEEE Robotics and Automation Magazine* (December 2001). See www.ieee.org. Also see www.me.berkeley.edu/hel/walkmach.htm.

24 FUTURE TECH

For a strongly pro-laser view, visit the Web site of the Academy for Laser Dentistry (www.laserdentistry.org) or the Institute for Laser Dentistry (www.laserdentistry.ca).

The American Dental Association (www.ada.org) gives the standard view of the dental profession toward laser dentistry.

26 THE PHYSICS OF . . . FOAM

Perkowitz, Sidney. *Universal Foam: Exploring the Science of Nature's Most Mysterious Substance.* New York: Alfred A. Knopf, 2001. And for the history and science of foam physics, visit www.tcd.ie/Physics/Foams.

30 WORKS IN PROGRESS

Kleinfeld, Judith S. "Could It Be a Big World After All?" Forthcoming in *Society* (2002). See www.uaf.edu/northern/big_world.html.

The Oracle of Bacon at Virginia Web site: www.cs.virginia.edu/oracle. Sign up for Duncan Watts's e-mail experiment: http://smallworld.sociology.columbia.edu/target.html. Also see Watts, Duncan J. *Small Worlds: The Dynamics of Networks Between Order and Randomness.* New Jersey: Princeton University Press, 1999.

32 SKY LIGHTS

Bad Astronomy: Misconceptions and Misuses Revealed, From Astrology to the Moon Landing "Hoax" by Philip C. Plait. New York: John Wiley & Sons, 2002. In addition to Plait's site (www.badastronomy.com), visit the astronomy news group FAQ: http://sciastro.astronomy.net.

36 WHAT WIPED OUT THE DINOSAURS?

Horner, Jack. *Dinosaurs Under the Big Sky.* Missoula, Montana: Mountain Press Publishing Company, 2001. This is a wonderful handbook for dinosaur lovers of all ages.

44 DOES THE UNIVERSE EXIST IF WE'RE NOT LOOKING?

Geons, Black Holes & Quantum Foam: A Life in Physics by John Archibald Wheeler with Kenneth Ford. New York: W. W. Norton & Company, 1998. Also check out Andrei Linde's Web site: http://physics.stanford.edu/linde.

50 TITAN'S TIME WARP

For more about Titan: www.seds.org/billa/tnp/titan.html. Also see NASA's *Cassini-Huygens* mission Web site: http://saturn.jpl.nasa.gov/cassini and the European Space Agency's *Huygens* Web site: http://sci.esa.int/huygens.

54 SIGHT UNSEEN

Mike May kept a journal in which he recorded some of his thoughts and experiences: www.senderogroup.com/status.htm.

The Discovery Channel created a documentary about May, including his first few moments of sight. Download a clip at Ione Fine's Web site: www-psy.ucsd.edu/~ifine/bandages_market.avi.

60 CAN TURTLES LIVE FOREVER?

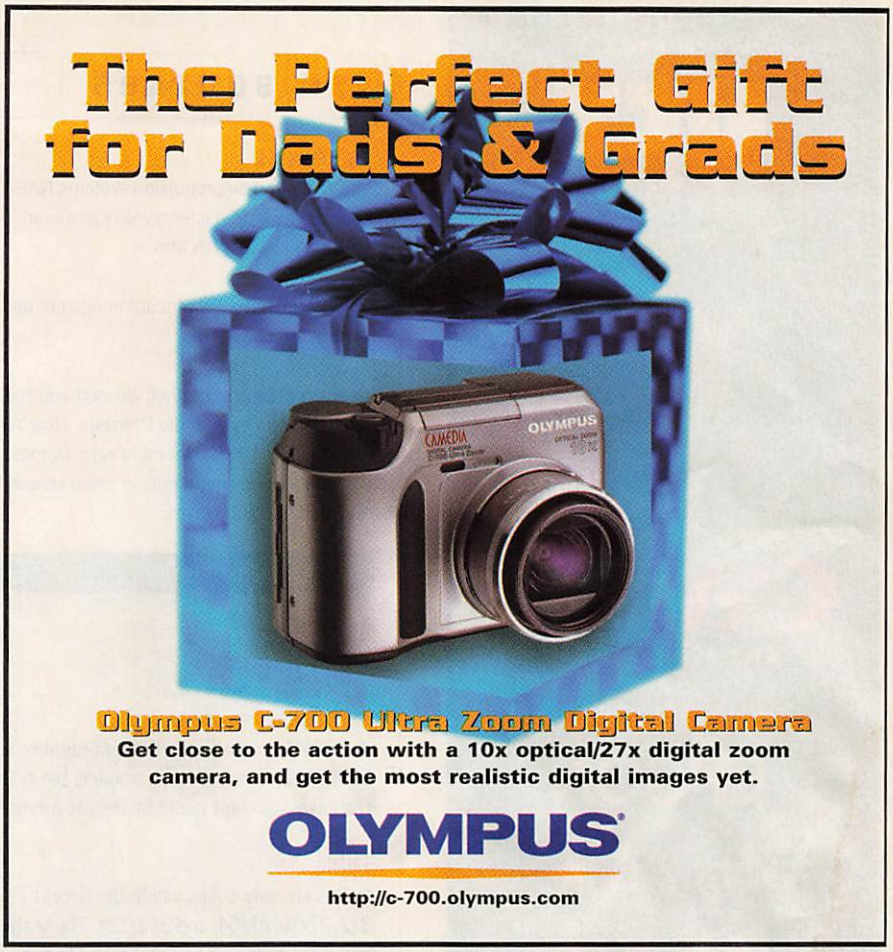
A good starting spot for turtle information can be found at http://emys.geo.orst.edu.

Their Blood Runs Cold by Whit Gibbons and Eugene P. Odum. Tuscaloosa: University of Alabama Press, 1983. A lively account of Gibbons's adventures as a field biologist.

Neurobiologist Caleb Finch sponsored a symposium on slow aging, and the papers were compiled into an issue of the journal *Experimental Gerontology* 36 (April 2001).

68 20 BIOTECH GENIUSES TO WATCH

For more about these biotech visionaries and their discoveries, see the following Web sites: **David Baker:** University of Washington laboratory, http://depts.washington.edu/bakerpg. **Sydney Brenner:** Institute of Molecular and Cell Biology's Fugu Genome Project, www.imcb.nus.edu.sg/fugu/fugu.html. **Charles Cantor:** Sequenom, www.sequenom.com. **Tom Cech:** University of Colorado, http://petunia.colorado.edu. **Elaine Fuchs:** University of Chicago, http://bmb.bsd.uchicago.edu/index3.html?content=faculty.html. **David Goeddel:** Tularik, www.tularik.com. **Corey Goodman:** Renovis, www.renovis.com. **William Haseltine:** Human Genome Sciences, www.hgsi.com. **Leroy Hood:** Institute for Systems Biology, www.systemsbiology.org. **Eric Lander:** Whitehead Institute Center for Genome Research, www.genome.wi.mit.edu. **Robert Langer:** MIT, http://web.mit.edu/beh/people/langer.htm. **Joshua Lederberg:** Professional profile, http://profiles.nlm.nih.gov/BB. **Mark Levin:** Millennium Pharmaceuticals, www.mlnm.com. **Arthur Levinson:** Genentech, www.gene.com. **George Rathmann:** Hyseq Pharmaceuticals, www.hyseq.com. **Gerald Rubin:** Howard Hughes Medical Institute, www.hhmi.org. **Stuart Schreiber:** Professional profile, www.chem.harvard.edu/faculty/schreiber.html. **Peter Schultz:** Professional profile, http://schultzweb.scripps.edu. **Craig Venter:** The Institute for Genomic Research, www.tigr.org. **George Whitesides:** Professional profile, www.chem.harvard.edu/faculty/whitesides.html.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76 REVIEWS

Learn about new propulsion systems NASA is cooking up: http://science.nasa.gov/headlines/y2000/ast11apr_1m.htm.

For top tips, see www.topspinning.com and www.byron.com/itsa.

Descartes' Error: Emotion, Reason and the Human Brain by Antonio Damasio. New York: Avon Books, 1995. Neurobiologist Damasio writes about developments in brain research and mind/body dualism.

80 BOGGLERS

These puzzles were inspired by *Donald Duck in Mathmagic Land* (Disney, 1959), a half-hour mathematics documentary available at educational stores and Web sites. Also see the Just Intonation Network Web page (www.dnai.com/~jinetwk) and a page compiled by Ron Knott of Surrey University: www.mcs.surrey.ac.uk/Personal/R.Knott/Fibonacci.

88 NEUROQUEST

Edwards, Betty. *The New Drawing on the Right Side of the Brain.* New York: J. P. Tarcher, 1999.

BOGGLERS SOLUTIONS

GOLDEN RULES

1. 2

2. 2.41421 . . . = $1 + \sqrt{2}$

3. 1.41421 . . . = $\sqrt{2}$

4. 1.32471 . . . , which is the real-number solution to the equation $x^3 - x - 1 = 0$.

5. 1.27202 . . . = $\sqrt{1/2 + \sqrt{5}/2}$, which is the real-number solution to the equation $x^4 - x^2 - 1 = 0$. This rectangle was first found by Robert Ammann.

TUNING UP

1. This six-note scale, which the Greeks called a hexachord, has only five distinct intervals: 9/8, 3/2, 27/16, 81/64, and 243/128. The scale was constructed by repeatedly multiplying 128 by 3/2 and dividing by 2 when necessary to keep all pitches within one octave.

2. Four distinct half steps. From smallest to largest: 25/24, 135/128, 16/15, and 27/25.

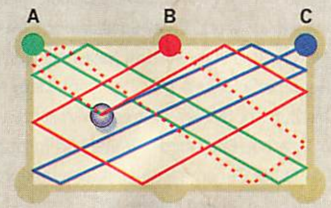
3a. The 16-note equal-tempered scale includes a note that best approximates the major third in a 12-tone scale in just intonation: 1.24186 . . .

3b. The 29-note equal-tempered scale has a note that best approximates the perfect fifth in a 12-tone scale in just intonation: 1.50129 . . .

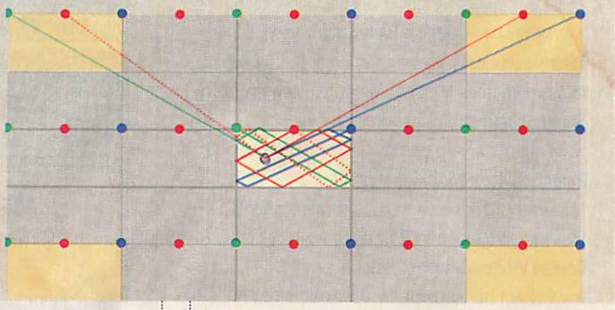
3c. The 41-note equal-tempered scale has a note that best approximates a major third (1.24580 . . .) and a perfect fifth (1.50042 . . .).

WORKING THE ANGLES

Shown in the figure at right are all the ways to bounce the ball off all four sides of the table and reach each of the three upper pockets. There are two solutions for the middle top pocket.



To figure out which of the paths to pocket B is shorter, imagine that the sides of the table are mirrored walls. If you were to look into the mirrors, you would see an infinite array of reflected tables. Draw mirrored copies of the pool table on all sides extending out two tables in all directions. A bouncing path on the table is equivalent to a straight path through the mirrored tables: Each path continues past the table's edge at the points where the ball has bounced off one of the sides. For the path to bounce off all four sides, it must end in one of the four yellow tables, yielding the four solutions to the original problem. Of the two paths to the red pocket, the dotted path on the left is slightly shorter, since the ball starts toward the left side of the table.



(continued from page 10)

act repulsively." Guth is touted as being in line for a Nobel Prize. I don't know what this means, but surely there is an irony!

PETER HAYDEN—Manchester, Missouri

Brad Lemley responds: *Guth says that a repulsive force exists in the universe—that there is ample evidence for the existence of a sort of antigravity that battles the better-known attractive gravity that we all experience. This repulsive force powered inflation 15 billion years ago, and a remnant of it persists, causing the expansion of the universe to accelerate over time. This is quite different from contending that all gravity acts repulsively.*

EXCEPTIONS TO THE RULE

In "Notes From a Parallel Universe," Jennifer Kahn writes that "cranks are pretty much never right." There are two notable exceptions. One was Robert Stirling, who invented the Stirling, or external combustion, engine. The other was Thomas Bayes, who developed the Bayes theorem, one of the most significant principles in probability theory. In particular, Bayes suffered the ridicule of mathematicians until his idea was eventually accepted.

SCOTT JACKSON—Irvine, California

Editor's note: *They're hardly the only cranks to be eventually proved correct. But we would point out that the Stirling engine is not exactly a sweeping success that has found its way into everyday life. (But we do hope inventor Dean Kamen will fix that when he installs them in his Segway personal transporter.)*

LEFT OUT

In April's Future Tech you mention that there is no naturally occurring material with left-handed optical properties. Actually, there is a beetle native to Central America that exhibits such properties—the jeweled scarab.

DAVE STOPP—Pittsburgh, Pennsylvania

Editor's note: *We've since learned that several scarab beetles exhibit this property.*

ERRATA

In "Guth's Grand Guess," we stated that Edward Tryon was an assistant professor at Columbia University in 1973. In fact, he was at Hunter College of the City University of New York that year, having left Columbia in 1971. In Sky Lights in our January issue, which was on the newsstand in early December, we stated that NASA was running a yearlong contest to name the Space InfraRed Telescope Facility. We hope you noticed, because the contest ended on December 20, 2001. Finally, we apologize to those of you who were frustrated by problem 6 in Counterexamples (Bogglers, May). The solution contradicts our statement "All answers are distinct positive whole numbers between 1 and 10."

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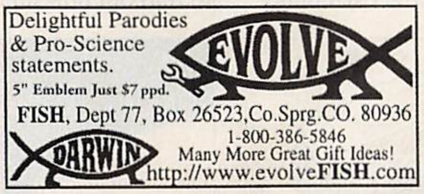

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11 GREATEST UNANSWERED PHYSICS QUESTIONS. Would you like some answers to the February 2002 issue? If so, go to **www.11questions.com** for answers and other concepts.

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YOUR INNER ARTIST

Unleash hidden spatial skills

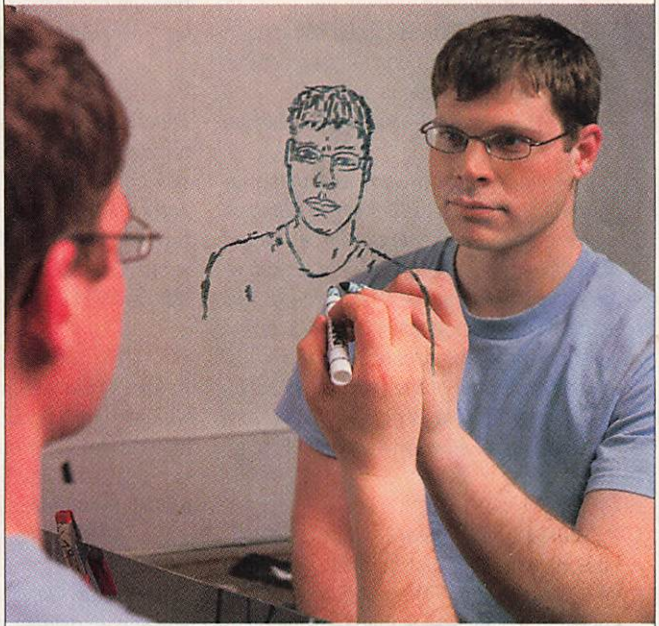
BY ERIC HASELTINE

NO DOUBT YOU'VE HEARD THAT HUMANS USE ONLY A SMALL percentage of their brain. The figure typically cited is 10 percent. There's no evidence that number is anywhere close to the truth, but there is research that suggests each of us has a lot of brainpower that isn't being accessed. The following experiments will help you tap into unused sources of creativity hidden deep within your own brain.

EXPERIMENT 1 Using a pencil and an eraser, make freehand copies of the drawings below. While sketching both figures, take care not to turn the magazine over or tilt your head.

Most likely, your sketch of Abraham Lincoln will be more realistic than the one of Ludwig van Beethoven. Betty Edwards, in her book *Drawing on the Right Side of the Brain,* speculates that the reason you don't routinely draw as well as you drew Lincoln is that your brain is like a unruly classroom in which an extremely vocal student often gets a disproportionate amount of attention. The loudmouthed culprit in this case is your left hemisphere. Edwards says it organizes the world into abstract, schematic symbols—such as the stylized eyes, noses, and mouths of children's drawings—instead of the true-to-life contours and spatial relationships that actually make up faces.

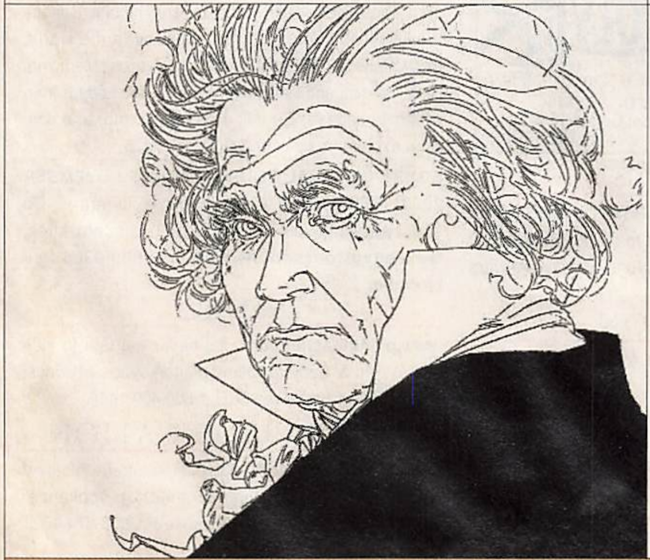
What your left brain lacks in spatial skills, it more than makes up for with aggressiveness, pushing your less dominant but spatially more talented right brain aside when you try to draw. When you draw an upside-down figure, however, the left hemisphere can't immediately classify what it sees. So the right hemisphere takes over and reproduces actual spatial information as opposed to abstract symbols.

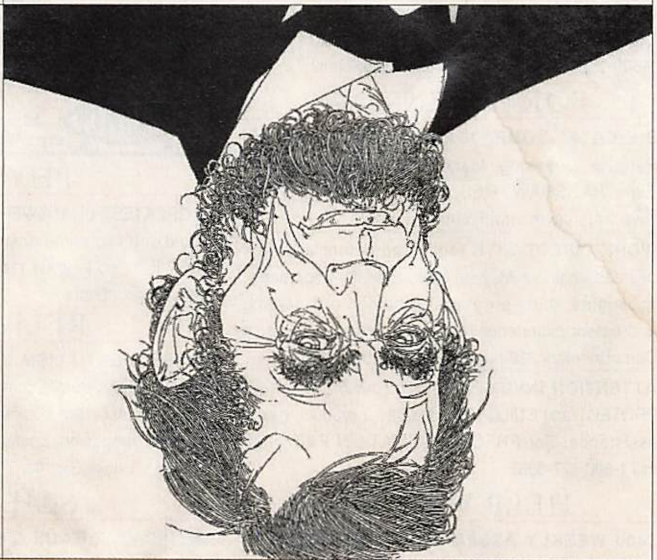


EXPERIMENT 2 Take a fine-tip washable ink marker and sit within arm's length of the bathroom mirror. Prop your chin on a box of facial tissue (or employ another means of steadying your head), then close one eye and slowly trace the reflection of your face on the mirror with the marker.

Within a few minutes you'll have a self-portrait that's probably a lot more realistic than you'd ever dreamed possible. That's because your left hemisphere knew immediately that the job of tracing facial contours wasn't worthy of its lofty symbolic talents, so it took a hike, leaving the childish job of messing up the mirror to its bohemian neighbor. (You can reinvigorate your left brain by assuring it that the ink *will* wash off.)

Masters such as Leonardo da Vinci used techniques akin to the mirror experiment to teach themselves to draw and to find out how much latent talent they really had. ☒





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